

**THE IMPACT OF INPUT DURING THE DESIGN OF
AN ASSISTIVE TECHNOLOGY PRODUCT**

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by

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THE IMPACT OF USER INPUT DURING THE DESIGN OF AN ASSISTIVE TECHNOLOGY PRODUCT

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LIST OF SYMBOLS AND ABBREVIATIONS

ABS	Australian Bureau of Statistics
AT	Assistive Technology
CATEA	Center for Assistive Technology and Environmental Access
CCN	CATEA Consumer Network
CE	Concurrent Engineering
DASH	Disabilities of the Arm, Shoulder and Hand
DFM	Design for Manufacturability
DSM	Design Structure Matrix
IRB	Institutional Review Board
NHPT	Nine Hole Peg Test
OT	Occupational Therapist
QFD	Quality Function Deployment
UCD	User Centered Design

SUMMARY

The design of products is a complex and expensive process. The design of everyday products can be challenging. When the product being designed is an assistive product it can become even more difficult. Companies that produce assistive products face all of the same design and business related issues of any other company along with many additional ones that can make the design of assistive devices even more challenging. This dissertation will examine the special challenges that are faced by designers of Assistive Technology (AT) products. It will then examine the design process and discuss how the design process itself can be utilized help address the challenges of designing AT devices. Finally, the results of a study to measure the effect of input during the design process will presented.

My personal interest is in studying and improving the process of design. I feel this is especially important in the design of AT. One of the study participants referred to people who do not require the use of AT as C.R.A.B.s, or Currently Regarded as Able Bodied. Nearly everyone in their lifetime will find a need to use an assistive device of some sort, whether because of the effects of age, accident or some other reason. Finding improvements in the design process is will benefit users and producers of AT in many ways. My hope is that this study will make a small contribution that will help advance design methods to help to encourage new innovation and enable the creation increasingly better products.

CHAPTER 1

INTRODUCTION

The main goal of an Assistive Technology (AT) product is to help a person enhance or replace some functionality that has been lost. This increased functionality can help users of AT become more independent and enjoy a better quality of life. Creating a product to meet these goals can be difficult. It requires knowing what a product needs to do to perform a particular task along with an understanding of the functional needs of the end user. Users of AT products may cover a very wide spectrum of abilities. A product that works perfectly for a user at one end of this spectrum may be inadequate for a user at the other end, even though the task is exactly the same. Understanding the needs of both the tasks and the users is often not trivial. This is just one of the many issues that make creating AT products challenging.

Considering the importance of an AT product in a user's life, a strong focus on functionality is very important. If a product does not work well or is unreliable, then it will not be able to do much to aid a user. But products, especially ones that are important to a user, need to be able to meet more than just the need to perform some task. An AT product is often central to the way a user interacts with others and important in the way others interact with a user. Additional needs such as desirability, social acceptability or satisfaction are areas where many AT products may not receive as much attention during design.

Focusing on new product research and development can be a challenge for many AT companies. There are many potential reasons for this, from the fact that many markets are small to limited resources to the potential expense in developing newer products and potential risks that selling new products can bring. Maybe products are perceived to be good enough with no need for changes. Of course there are companies that do invest greatly in the development of new products. Even so, many AT products might still be

described as institutional; that is, more focused on providing functionality with little regard for other potential user needs. This can contribute to low levels of satisfaction with a product and low satisfaction is known to be a contributor to the high level of abandonment seen with AT products.

The focus of this dissertation is in finding ways to create better AT products through improvements to the AT product design process. Specifically, it will investigate how different types of input supplied during the design of an AT device affect how the final product is evaluated by users. Understanding the impact of input can provide many opportunities for improvements.

Chapter 2 begins with an examination of the challenges that designers can face in fully learning about and understanding a design problem in AT. The issues of understanding user wants and abilities are covered next. Some of the challenges faced by AT companies are covered next, including the production of AT products, effects of organizations and challenges of innovation.

Chapter 3 begins a discussion of the design process. The various activities that are performed during the design of a product are described along with how the approaches and design methodologies that are used can affect how those activities are carried out. A design methodology that addresses many of the challenges in AT is discussed next. Finally, the chapter covers how input is commonly utilized during design and concludes with a description of how a good AT product might be evaluated.

Chapter 4 describes a study that was conducted to measure how different types of input provided during design of an AT device affect the final product. Several design teams were given the task of designing an AT product. Each was provided a different type of input that is commonly used in AT design during the process. The object was to test the hypothesis that input that comes more directly from an end user will result in a product that is more effective and satisfactory than products designed with input that is less closely associated with an end user. Much literature on AT design focuses on the

need to involve users to produce a more successful design. It seems to be a logical assumption, however whether direct user input has a greater effect on the resulting AT product than other types of input (such as simulation tools) has never been directly measured. The study seeks to test this assumption and attempt to measure the effect size of different types of design input on the effectiveness and satisfaction of the product.

Finally the results are discussed along with how they might be useful in AT design. The study does find that direct user input seems to have the greatest measurable effect on both satisfaction and effectiveness of a product. It is also found that other types of input can have similarly large effects on the design outcome while others do not have the type of effect that might be expected at all. Some potentially useful implications are discussed along with how they might be utilized to improve the design of AT products. There are some important limitations to this study, but it is intended to be a small step in the understanding of design input. Hopefully, it can be a starting point for further investigation that can lead to more effective design methods for producers of AT and better products for users of AT.

CHAPTER 2

CHALLENGES OF DESIGNING ASSISTIVE TECHNOLOGY

2.1 Understanding User Needs

The Assistive Technology act of 1998 defines an Assistive Technology (AT) device as “any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase or improve functional capabilities of individuals with disabilities (PL100-407)”. This definition itself appears simple and clear. However, behind the simplicity hide many challenges to creating AT devices.

One of the first of these is gaining the perspective to understand the needs of the users that will eventually use the product. The designer must know what users are capable of and how the product being designed will be used. This way the designer can be sure that users will be able to use it to perform a task successfully. In most cases, the designer of a product and the eventual user are not the same, so there is naturally a gap in understanding between the way a designer will view a task and the way that a user will view a task. This might be illustrated by the following figure.

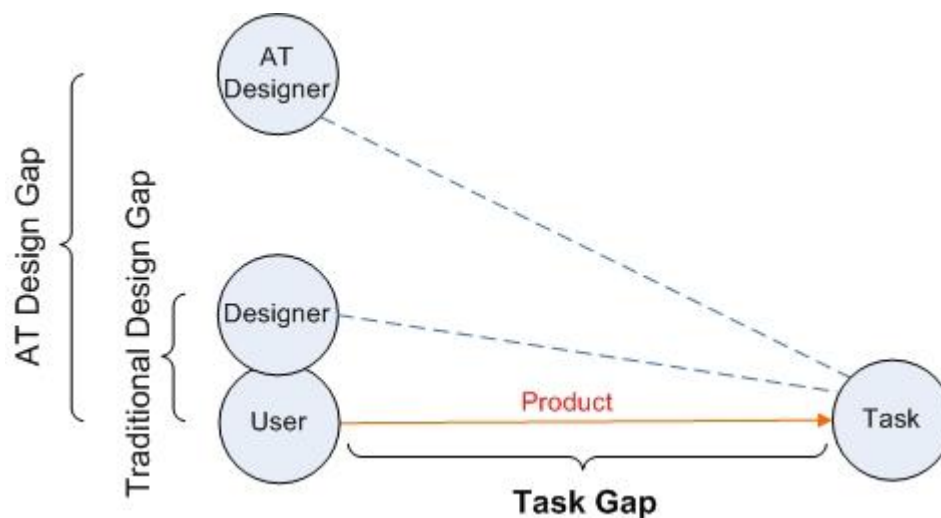


Figure 2.1. Illustration of the relatively small gap between the user and designer perspectives in traditional and AT product design

Figure 2-1 illustrates the gaps in understanding that can exist between a user and a designer. The user is separated from the task by a gap; this is the ‘Task Gap’. The designer’s goal is to design a product that will bridge this gap and allow a user to perform the task by using the product. The first step is for the designer to understand the requirements of the task. The requirements define the functionality that the product needs to have so that it can perform the task. The second step is in understanding how the user will utilize the product. This is important because if the user can not actually use the product it will be of little use to them, even if the product is actually capable of performing the task. If a product works, then how could it not be useful? This can happen if designers create a product that works from their own perspective of how a task should be performed (the dotted lines in Figure 2.1). This difference in perspective between user and designer in traditional design is the “Traditional Design Gap”.

Designers are trained to imagine themselves “in the shoes” of users (Nieusma 2004) while designing. This way, a designer can design as if from an end user’s perspective so that the final product will perform a task in a way that works best for the user. In the design of most products, the designers and the end users are typically very similar with respect to their abilities. The capabilities the end user has to perform a task are not much different from those of the designer. The designer must still consider preferences and the environment of the user. These considerations can be challenging, but fundamentally the user and designer are often very similar, so the difference (gap) in perception between user and designer is relatively small.

In the design of an AT product, the relationship between the task, user and designer is typically much different. This is illustrated by the AT Design Gap in Figure 2.1. Most designers, including designers of AT, are not disabled themselves. It is much more difficult for a designer to imagine themselves in the shoes of a user that may user have lost some basic ability to interact with the world that the designer could ordinarily take

for granted. A non-disabled designer may have a descriptive understanding of a disabled user's needs, but it is much more difficult for a non-disabled designer to understand the implications of having to live with those needs from day to day (Nieusma 2004). If an AT product is created more from a designer's perspective, then it is much less likely to be useful to the eventual user.

AT is a case where the information about the need is very closely held by the user. It is very difficult to transfer closely held information about a need from one person to another. This has been described by Eric von Hippel as "sticky information." The stickiness of a unit of information is defined by the incremental expenditure needed to move it to a specific location so that it is in a form that is useful to the information seeker (such as a designer). When the effort required to move the information is low, then the stickiness is low; when the effort is high, then the stickiness is high (von Hippel 1994).

The reason behind information stickiness may have been best described by Michael Polanyi. It is not always possible to simply pass knowledge from one to another by description. Instead, true knowledge of something is more like an art and is often passed from one person to another by example, such as from a master to an apprentice (Polanyi, 1958). He gives a several examples to illustrate. One example is of riding a bicycle. It is possible to describe the physical rules of riding a bicycle such as momentum, balance, gravity and centrifugal force. If you are riding a bicycle and begin to fall to the right, then the correct action is to turn to the right. The momentum of the bike through the curve creates a centrifugal force to the left which counteracts the force of gravity and pushes the cyclist back to an upright position. The opposite can be done if the cyclist begins falling to the left. You could then describe riding a bicycle as following a series of curves that keeps the rider upright. To someone who has never ridden a bicycle, simply explaining or giving them the formulas and rules that describe how to stay upright would not mean that they would be able to ride it. Nobody would be able to perform the required calculations in real time to inform them of what to do. The rules themselves

may be useful, but real practical knowledge of riding a bicycle only comes through practice. Another example is very relevant to our topic here:

If, as seeing men, we are blindfolded, we cannot find our way about with a stick as skillfully as a blind man does who has practiced it for a long time. We can feel that the stick hits something from time to time but cannot correlate these events. We can learn to do this only by an intelligent effort at constructing a coherent perception of the things hit by the stick. We then gradually cease to feel a series of jerks in our fingers as such – as we will still do in our first clumsy trials – but experience them as the presence of obstacles of certain hardness and shape, placed at a certain distance, at the point of our stick. (Polyani, 1958. p 61)

There are many strategies that designers use to reduce the gap between themselves and users. One is through the use of tools to simulate a user's abilities, such as Ford's 'Third Age Suit' which simulates the reductions in strength, flexibility, vision and other abilities that come with aging. The suit allows designers to experience the world in a way similar to a much older person. While such aids are useful, they do not eliminate the User Gap and can be misleading. This is because the designer will take off the suit and return to normal. Learning to cope with a limitation over time or knowing what it is like for one sense to become enhanced to compensate for the loss of another can not be simulated (Clarkson, Coleman et al. 2003).

Designers also might use input from professional therapists. Of course, a therapist will not have exactly the same perspective as a user, but experience working with users and helping them find solutions to day to day problems make therapists a good source of information. Therapists can provide a unique perspective and can be particularly helpful when it is not possible to collect input directly from end users. As an example, consider the development of devices for users with dementia (Orpwood, Gibbs et al. 2004).

Dementia is characterized by severe memory loss and inability to learn new things. This

makes designing devices with new features challenging because anything new must operate, from the user's perspective, in exactly the same way as devices with which they are already familiar. This also typically prevents them from being able to provide direct input. Needs for these users initially were gathered from caregivers and used to develop prototypes that were appropriate to actually be used by the end users. Observation was then used, which can be a useful method of learning about a problem, to gain a more direct understanding of the needs and problems encountered by the users. Even though the initial needs were provided by people who provide constant direct care for the users, the direct testing uncovered many critical needs that needed to be incorporated into the products to make them useful for the users.

From these few examples we can see how the gap in perception between users and designers can be an obstacle. A listing of requirements that describe what should be done to perform a task can be useful but by themselves are probably not enough to design a successful AT product. Understanding of a user's point of view is also critical. But like riding a bike or finding your way with a stick, an understanding of needs that might arise from living without some ability cannot be easily transferred to a designer through simple description. Although through understanding of need information may only come through experience, there are various tools and techniques that can be used to give designers a better understanding and make the need information less sticky.

2.2 Understanding Stakeholder Wants

Another challenging aspect to AT design is that there will often be more stakeholders involved compared to a regular commercial product. The AT device user is one of several stakeholders that might include family members, health care providers, employers, manufacturers, insurance providers and others. Sometimes an AT product must work as well for these groups as it does for the user. Often the capabilities that an AT product improves for a user involves interaction between the user and others. If these

needs are not considered during a product's design it can lead to a frustrating experience for the user and everyone else.

There is a strong focus on ensuring that a product can effectively perform a task. Considering the importance of AT products in the lives of users and those around them, this focus is good. This focus has led some to observe that many AT products seem to be engineered more than they are designed. In these cases little thought appears to be put into meeting the psychological needs of the user or what the impact that the design of the product will have on those who use it (Allen 2005). Perhaps this is why many AT devices have an institutional feel to their design. This is unfortunate, since most users will generally prefer not to use a device if they feel that it brings unwanted attention to their condition (Hocking 1999).

This is an important consideration because the purchaser and user of an AT product is not always the same person. When a regular product is purchased, the user and purchaser is generally the same person and other people are not involved. The purchaser will browse and compare products until finding one that fits their needs and desires. Whether the purchase is discretionary or is something that is really needed, the product chosen will be the one that is the right combination of functionality and desirability. Even if a third party is involved, such as buying a gift, the buyer's mind is generally most concerned what the recipient will like the best.

The process of buying an AT product might include family members, health care providers, employers, insurance providers and others. If the purchase is being made by a third party, what the user wants may not be a consideration. The main question will most likely be: what does the user need? Disabled users by and large have the same types of desires for products and services as most any non-disabled person (Clarkson, Coleman et al. 2003). This means that like anyone else, they will prefer a product that they like. Alan Newell reminds us that in many ways, people define who they are and express themselves through the things that they own. But things that people need do not

necessarily have the same requirement to be made beautifully as things that people want (Newell 2003). The only choice the user of an AT product may have is between using the product to re-gain functionality or independence (even if they don't like the product) and not using the product at all. If the design of an AT product is not sensitive to these issues, the resulting product itself can be disabling (Cowan and Turner-Smith 1999).

If an AT device has an unpleasant appearance the user is much more likely to react negatively to it. Some of this has to do with aesthetics but there is also another of desires to consider. If the user is born with a disability, they are more likely look beyond physical appearance of a device and see new abilities that are available to them through its use. If the user acquires their disability later in life, they might see it more as a reminder of lost abilities for which a device cannot fully replace (Hocking 1999).

All this is important because if a user doesn't want a device they are less likely to use it. If an AT product functionally performs well but is not actually used by a user who needs it, then that product is arguably a failure. Even though they are meant to help, many AT products are un-used or under used (Clarkson, Coleman et al. 2003). Many studies have documented this issue. One found that 44% of users that owned a portable ramp actually used it less than one time per week (Choi 2007). This is a fairly typical finding. On average, 30 percent of all assistive devices are unused (Wessels, Dijcks et al. 2003). Many factors affect this abandonment rate. AT devices are not always chosen by their users, but if they are involved in the selection process the rate is lower (Riemer-Reiss and Wacker). The issue of AT abandonment is important since an unused device cannot help to improve a user's quality of life. When a user abandons a device there is also a potential social cost. Third party payers such as private insurance or government assistance lose revenue when it is replaced by paying for a replacement. These losses can be passed on in the form of higher insurance premiums, higher taxes or more restrictive approval policies that make it even harder to sell AT devices (Jain, Usiak et al. 1996).

2.3 Understanding Users' Abilities

In commercial product design, a relatively small group of users can represent a large majority of people. For example, to determine if a product is likely to be difficult to use, only a relatively small number of users (perhaps less than 10) are needed to find most of the usability problems that are likely to be encountered by people who will use it (Nielsen 1993). This is possible because most non-disabled people are very uniform in the way that they interact with the world. What works for one group of users generally works for everyone else. This approach is more complicated in AT design because the abilities from one user to another can be very different.

The users of AT products represent a continuum of abilities, from those with slight to moderate disabilities who may have more general needs to those with more severe disabilities who may have very unique and specific needs. An AT product may function great for one group of users but another group of users may not be able to use the product's functionality at all because they have a more severe disability. Even though the task may be the same for both groups, a product may be worthless to one of the groups because of the difference in the user's abilities. In non-AT product design, the user side of the development equation is much less variable than in AT product design.

Cook and Hussey (Cook and Hussey 1995) described how this variability is addressed in AT products. They outlined several categories which can be used to describe AT products and how they can be used to meet the needs of users with a wide spectrum of different needs and abilities. Some can be considered appliances, which require no special skills to operate, while others are more like tools, which require the user to develop special skills to operate effectively. AT products can also be said to employ minimal or maximal technology to describe the level of function the product provides to the user. A minimal technology is one that assists its user in performing a task better. It helps to improve abilities that the user still has. A maximal technology is one that completely replaces some function or ability that the user would not have at all without

the device. An AT product may also be described as general or specific. A general product is one that can be used across a wide range of applications while a specific product is one that is designed to improve performance in very specific area. Finally, there is commercial vs. custom technology. A commercial technology is defined as one that is mass produced and designed for the general population. Whenever possible, a user's needs are met by commercial technology. If this is not possible, a device that is mass produced but specifically designed for users with disabilities may be used. This is called a special commercially available device. Finally, if neither of these options meets a user's need, a device that may be produced specifically for the needs of the individual user. This is called a fully customized device.

It is unlikely that a single AT product will be appropriate for all users that might need to perform a task. A user might require a very specialized device, depending on their abilities. The need for customization of a product to work for a user is a major concern in AT (it is important in non-AT design but is more of a second order concern). Successfully meeting the needs of as many users as possible is a challenge not just for a designer, but also for the company that produces the product.

2.4 The Production of AT Products

AT devices, like most other products, are produced and sold by companies. This means that the normal needs of a business can add more complications to producing an AT product. Many AT companies tend to be relatively small (though there are certainly AT companies that are very large). This is because the markets for assistive products are often smaller, niche markets (Harwin 1998; Cowan and Turner-Smith 1999). For assistive devices designed for a very specific purpose, the market for it may be very small. These devices may not be mass produced and so the AT company does not gain the same cost reducing benefits that mass production brings to many consumer products. AT products of a more general nature such as a cane or crutch can take advantage of

mass production due to their standard form and larger market. A crutch for example might be useful for a large portion of the disabled population and also see demand from the non-disabled market (such as a person who must use a crutch temporarily while recovering from an injury). Less general use products are often produced by a custom manufacturing process that is flexible and more efficient for smaller quantities. The process must be flexible since they may require customization during production to fit the user. A product may be broken up into parts that can be manufactured easily and parts that require special care. An example of this would be an artificial limb. The limb itself has a defined shape and so is very easy to produce. The complex part is the end that is fitted to the user since each fitting must be tailored to a particular user (Harwin 1998).

Manufacturing costs are an important component in the cost of any product. Smaller production runs and device customization tend to increase a product's price. This is a concern in AT due to the economic condition of many people with disabilities. 24 percent of people with a non-severe disability are unemployed. For people with severe disabilities, this figure is 76.8 percent (McNeil 1992). Many users must purchase AT products with state or federal government aid or through insurance. This presents problems both for users and manufacturers. For example, users may have to work with government agencies so that they can afford to purchase the AT product. The manufacturer may also need to work with the agency to certify their product so that is put on a list of supported products. The product list may or may not be up to date on available technology or how it is useful (US_Department_of_Commerce 2003). This limits both the user's choice and a company's ability to sell a product.

The smaller size of most AT companies means that additional costs or delays during design and manufacture of a product can have a relatively large impact. The most important factors in many product development projects are development costs and time to market (Bayus 1997). These are important because of the simple fact that any company that makes money by producing a product will want it to be as economically

successful as possible. Because of the sticky nature of the need information in AT, extra effort during the design of a product may be required to fully understand a task. If need information is collected from users, this can take a great deal of time (Green and Jordan 1999) which increases the overall development time. The extra development costs can be large, and there is also an issue of getting the product to market quickly. In some cases, delaying the release of a product may reduce the total after tax profit generated over the lifetime of a product by one third (Wind and Mahajan 1997). The impact of product delays can sometimes be felt immediately. In the case of the auto industry, each day a new model is delayed could cost one million dollars (Clark, Chew et al. 1987; Ha and Porteus 1995). Of course, most AT companies do not operate anywhere close to the same scale as an automaker, but the same principles of reduced profitability and lost revenue apply to AT.

2.5 Organizational Influences and Innovation

The speed of the development cycle is not the only factor that a company must consider. When pressured develop a product more quickly there are trade-offs that often must be made. A product development manager might say that it can be done good, fast, or cheap; pick any two (Bayus 1997). The tradeoffs in AT may be more challenging in some ways. The product must be good and reliable because of its importance to a user. Creating a good AT product takes time due to the difficulty of translating sticky need information into a useful product. At the same time, it needs to be done inexpensively so that end users can afford to purchase the product and generate revenue. It seems almost impossible to pick two of the options at the expense of the other one. If an AT product is produced too fast, it may be cheap but there won't be enough time during design to fully understand the need, so it is unlikely to be good. If the goal is for the product to be good, then more time will likely be necessary during design which will make it more expensive.

A better saying for an AT product might be that it can be done good, fast, or cheap; pick one.

An advantage that an organization has is that it can learn how to do things better over time. This learning not only takes place on an individual level (such as a single designer), it includes a company's the managerial and technical systems that make up an organizations values (Leonard-Barton 1992). These values are what help give some companies competitive advantage over others within certain markets. Even though people come and go from a company, the values tend to persist as they are passed on to others through the way that the organization conducts its operations. In other words, over time a successful organization will learn how to perform efficiently and will pass that knowledge along even as individual members change. For an AT company this can be a good thing. For example, if an AT company is focused on producing products to do a certain kinds of tasks, over time it will gain a better understanding of how to meet the needs of those tasks. That understanding will be pass on through the organization and improved over time making the company even better at meeting those needs.

As an organization learns this organizational memory will affect how incoming information is interpreted and utilized in the product development process (Moorman and Miner 1997). This can be seen in how a user and an organization might view a product solution to a particular design problem. Users are generally interested in getting the best possible solution but do not care as much about exactly how it is delivered. Manufacturers like to supply custom solutions to users while utilizing their own organizational expertise and capabilities. This expertise creates a strong incentive for manufacturers to convince users that the best type of solution is the one in which they specialize (von Hippel 2005).

If nothing else is changing, organizational learning can help make a company better at its specialty. Needs and technology can change often, and if this change happens too fast, an organizations skills can become a liability. A good illustration of this is a study of the

computer hard drive industry (Christensen and Bower 1996). Between 1975 and 1990, the industry experienced rapid technological change. The investigators found that companies that were the leaders in the drive market were consistently not able to adapt to and take advantage of new innovations in technology. The result was that a new, smaller company was able to enter the market and become the dominant market leader. One of the main reasons for this appears to be the allocation of development resources. For an established company, it is much more profitable to provide for the needs of large, established customers. These customers are not the ones that initially adopt new technologies and so development resources are best spent on improving existing technologies their needs. Committing limited resources to a new technology that has limited demand is not cost effective. However, as the new technology grows, it can begin to change the market as more people begin to adopt it. The company pioneering the new technology grows along with the market in both size and experience. The original market leader tended to incrementally improve the original technology as long as possible since that is what they are able to do best. By the time they are forced to change to the newer technology, they are far behind the newer company in both experience and market share. Essentially, a small new company entering the market with a disruptive innovation was able to leap ahead of and replace the established market leader.

The AT industry and the computer hard drive industry are very different, but there are two important points that are applicable. The first is that regardless of the industry, technology is always changing. It is impossible to predict when a new technology will be developed and applied in a way that will make doing something better, faster or easier. This is the definition of innovation. Innovation can cause large fundamental changes in the way things are done (often called disruptive or radical innovation) or it may cause smaller changes (often called incremental innovation), but it can happen in any industry at any time. The second point is that when innovation changes things, it can be difficult for an organization to adapt. This is because there is stickiness to outside technical

information. In other words, it can simply be hard to learn a new way of doing things because a organization's or an individual's capacity to absorb new, outside technical information is largely a function of prior related knowledge (Cohen and Levinthal 1990).

New product innovation provides one possible way to address the problem of choosing between good, fast or cheap in AT design. As in the hard drive example, new innovations often help to make a product better, easier (faster) to produce and cheaper all at the same time. The innovation itself does not necessarily need to be radical. In fact, most new product innovations are incremental in nature (Hollander 1965)(Levitt 1966) and there is much less risk to a company in developing an incremental innovation (Kleinschmidt and Cooper 1991). Even with the potential benefit new innovations could bring to both the company and to end users, in a survey of AT companies the US Department of Commerce found that 60% of AT companies said that research and development was not a significant part of their operations (Commerce 2003). Research and new development can be expensive and new products potentially risky. Risk with new products will almost certainly always be a factor in product development. One possible way to encourage the development of new innovations in AT is by finding ways to improve the design process.

CHAPTER 3

THE DESIGN PROCESS

There are three basic steps that make up the design of practically any product: find a problem, design a solution to the problem, build the solution. Product design is not only about the needs and requirements of a given task, there are other issues related to things such as the market for a product, balancing the needs of multiple stakeholders and perceptions inherent to an organization's way of doing business. All of these and other issues relevant to the process of designing a product must be managed properly for a product to be created. This is done through a design methodology.

3.1 Basic Design Methodology

A Design Methodology is a framework of steps that is designed to be a guide for all of the activities that happen during the design process. Now, there is no such thing as a 'standard' design process because it is almost always described in a slightly different way by many sources (Cross 1994; Borja de Mozota 2003; Ulrich and Eppinger 2003). Even so, design methods almost always contain the same basic steps/phases: Planning/Idea Generation, Concept Development, System Design, Detail Design, Testing/Trial and Manufacture.

During the Idea Generation phase, ideas for potential new products are gathered and examined. The goal is to identify the best ideas with the highest potential payoff to develop into a product. This phase has been described as a kind of funnel (Wheelwright and Clark 1992) where the top is wide and the bottom is narrow. This allows for the most ideas to be examined, but since resources are always limited, only the best ones make it through to be considered for development. Potential ideas may come from users, but they are often more likely to originate from within a company such as from a research and development group, as an offshoot from another project, from market research or

from reaction to competition. One of the most important factors at this stage is a company's business strategy since any idea that moves past this stage must fit in with it.

Once an idea is chosen for development, it enters the Concept Development phase. The three main activities during this phase are the identification of customer needs, the generation and selection of a concept and testing a selected concept. Gathering customer needs often involves focus groups and other methods to find out directly what they would like and need in the proposed product. Once gathered and analyzed, the needs are used to generate specifications for the product. The specifications translate the needs into precise functional definitions of what the product must be able to do to meet those needs. From this point, design concepts are created to show different product possibilities that can meet the specifications. Finally, the best concepts are then tested, often by surveying potential customers to get their impression of the concepts. They can be revised and re-tested until a concept suitable for the next phase is identified. Users are often highly involved in this phase since it is important to make sure that important stakeholder needs are not missed before moving to the next phase of development.

That next phase is System Design. System Design is when the specifics of how the product will actually deliver the desired functionality are implemented. The actual functional components, the basic form and how everything will work together are defined. User input is most often not collected during system design. However, it may not be possible to gather all of a product's needs during Concept Development. This can be particularly true for AT products. Remember back to the example of developing a product for users with dementia. Direct input could only be obtained through observation after a highly finished prototype was created that was suitable to be used by the end users.

After the required functionality has been implemented, the product enters the Detail Design phase. This is when final aspects of usability issues and aesthetics are refined. Often, these are details which do not directly affect the basic functionality. This stage

ensures that things like user interfaces are simple and intuitive or that the product reflects the company's corporate image. It is also a critically important step since a product may have great functionality, but if it is difficult to use or unappealing it will have a much lower chance of succeeding in the market.

The Testing/Trial phase involves users in tests and trials of a product. The tests and trials of this phase are not necessarily geared toward making changes to the product (these are done in previous stages) but are more focused issues related to packaging, marketing and distribution of the product.

Finally, the Manufacture/Launch phase is where the product is actually produced for the market. For manufacturing to be successful it must be possible to actually build the product and to do it cost effectively. The manufacturability and cost of producing the product are directly affected by decisions made earlier in the design process. Because of this, manufacturing issues are often a part of the planning or earlier phases. This is called Manufacturing Development or Design for Manufacturability (DFM) (Ulrich and Eppinger 2003) and helps to ensure that there are no surprises during manufacturing by planning for tooling and other issues related to producing the product through all stages of design.

3.2 Design Activities

During the course of each phase, there are a number of activities that take place. These activities are actions that are performed by various actors involved in the design process. Activities can be anything from marketing activities or management decisions to more 'designer-y' things like collecting user input or creating prototypes. These activities are important because it has been shown that products tend to have a higher rate of success if their development follows a defined process that includes certain best practice activities that are not skipped (Griffin 1997). These best practice activities include Strategy Development for the product, Concept Generation, Concept Screening,

Business Analysis, Development, Test and Validation, Manufacturing Development, and Commercialization.

The phases of the design process that these activities commonly take place are shown in Figure 3.1. There are some cases where the activities that are conducted depend on the type of thing that is being designed. For example, the development of a service or a piece of software may not include Manufacturing Development since the end result is not actually a physical product that will need to be manufactured. These activities not only help increase the success rate of the final product they but also contribute to much more effective use of resources during a design project. For example, Business Analysis and Strategy Development at the beginning of the process answer questions such as: Which ideas fit in with the overall strategy of the company? Do we have the expertise and know-how to successfully develop and later support the product? Is there a market for the idea that will make developing it into a product worthwhile? These just some of the very important questions that must be part of the overall design process. Depending on the answer to them the process will not continue beyond exploring ideas. A lot of time and effort might be wasted learning about a design problem (and trying to learn the sticky information about it) for a product idea that never should have been more than an idea if these activities are skipped.

Activities take place through the entire design process and receive input from many sources such as management, marketing, manufacturing, designers or users. A discussion of each is beyond our scope here, but various views on how these activities interplay with each other can be found in many texts on design, such as (McGrath, Anthony et al. 1992), (Borja de Mozota 2003), (Cross 1994) or (Ulrich and Eppinger 2003).

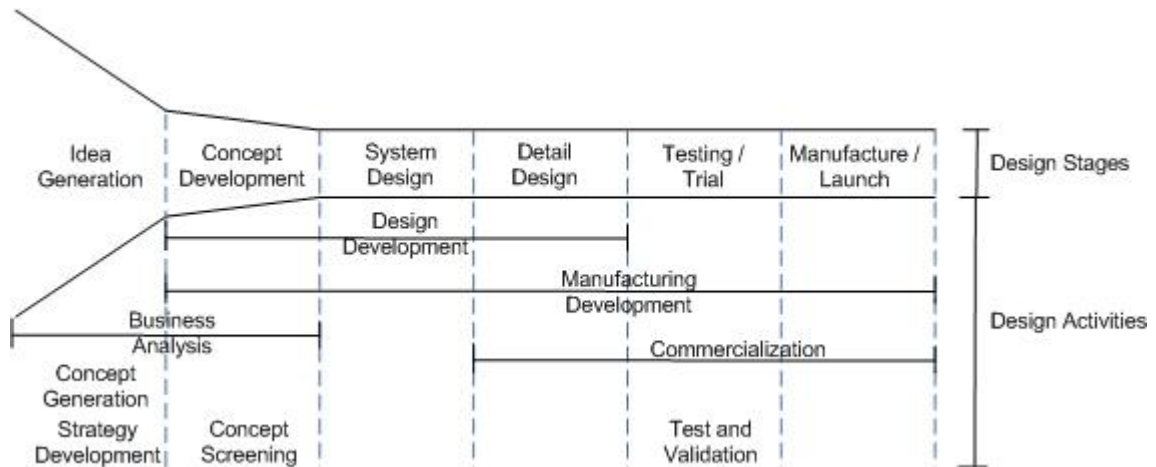


Figure 3.1. A generic design process with best practices activities and the stages in which they are typically performed

A true design methodology is a guide through the phases of the steps in the design process AND the activities that should be performed to increase the chances of creating a successful product. There are many different ways to describe how to do this and many different design methodologies have been created to help guide and direct the product design process. Some common methodologies employed during design include Stage-gate method (Cooper 1990), Quality Function Deployment (QFD) (Griffin and Hauser 1993; Kaulio 1998) and Agile Development (Beck, Beedle et al. 2001). Each of these breaks up and organizes the design process a little differently. For example, stage-gate breaks up the process into sequential stages with a quality control ‘gate’ in between each. The design does not move to the next phase until the quality requirements defined by the gate are satisfied. QFD uses a method involving a series of matrices to map customer needs (called the Voice of the Customer) to specific attributes of a design. The customer input is collected at the beginning and used throughout the design process. This allows design to be focused on specific areas that address customer needs and helps ensure that all design decisions are customer focused. Agile development takes a different approach. It breaks up the design into individual modules that represent part of the overall functionality. Each module is then developed independently, using previously completed

modules as the starting point. The goal is to deliver a working product quickly with functionality being added incrementally as new modules are designed and incorporated. One methodology might be more useful to a particular industry or company than another, but in the end, each methodology guides the design through the same phases as the generic design process.

3.3 Design Philosophy

There is one final aspect to the design process that I like to call the philosophy of design. The design philosophy simply describes how the different actors involved in the design process interact and their relative importance to each other. The design philosophy might also be thought of as the overall approach to doing design. Where the methodology defines the steps to perform, the philosophy suggests how to go about doing them and can affect all other aspects of the design process (Figure 3.2). A couple of examples might be helpful to illustrate.

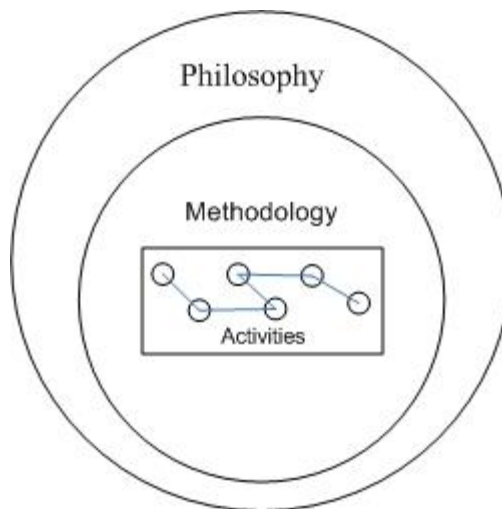


Figure 3.2: The relationship between design philosophy, design methodology, and design activities

Concurrent Engineering (CE) (Clark and Fujimoto 1989; McGrath, Anthony et al. 1992; Swink, Sandvig et al. 1996) is a way of organizing resources so that the design

steps are performed in a cross-functional manner. CE does not necessarily define the steps to be carried out during design process (i.e. concept generation, system design, etc). It is more focused on how those steps are carried out. In CE control and responsibility for development are shared by all groups through each phase of design. The product and processes associated with it, such as manufacturing, service and distribution; are all developed simultaneously. Design decisions that may impact multiple groups can thus be made by collaboration within the cross-functional team. Each group involved is represented and takes part in all decisions. This helps to reduce the complexity that can be introduced in design when information must be transferred from one group to another. The cross-functional approach helps to reduce the need for information transfer between specialized teams and can cause a corresponding reduction in the complexity of a design project.

Another example of a design philosophy is User Centered Design (UCD). UCD seeks to actively involve users in the design process with the goal of better understanding requirements and improving evaluation of designs (Mao, Vredenburg et al. 2005). The level of user involvement can be at many different levels, from a more passive role (such as providing input through interviews or focus groups) all the way to actually becoming the main decision makers in the design process.

A design philosophy is a compliment to a methodology. For example, principles of concurrent engineering can be applied to QFD. The normal steps involved in QFD are still performed in a multifunctional way. User centered design could be applied to a stage-gate method so that users are more integrated into the decision making process as a product is developed. The point here is that a particular methodology and philosophy can be chosen so that it is the best fit for a particular situation.

3.4 Design Methods in AT

Now we can relate this back to AT. At one point or another, just about every imaginable design methodology has been utilized to successfully design an AT product. Considering the challenges in AT design, it may not be surprising that approach or philosophy of design that is often chosen is user centered (Seale, McCreddie et al. 2002; Cassim and Dong 2003; Cassim 2004; Orpwood, Gibbs et al. 2004). The act of including users in the design process by itself is not necessarily enough to ensure that all aspects of a user's needs are collected. This would be kind of like following the generic design process without being aware of all of the activities that must take place. There must be some set of steps to follow that help ensure that all of the various aspects of a user's needs are addressed. We already know that it is not enough for a product to simply perform a task but it also should be acceptable, desirable, easy to use, etc.

There is currently no such thing as a standard design methodology for AT. However, (Keates and Clarkston 2003) have outlined a series of steps that can be included in AT design so that areas of particular concern for an AT product are addressed. They describe a 7-level design approach to inclusive design that is divided into three stages (Figure 3.3):

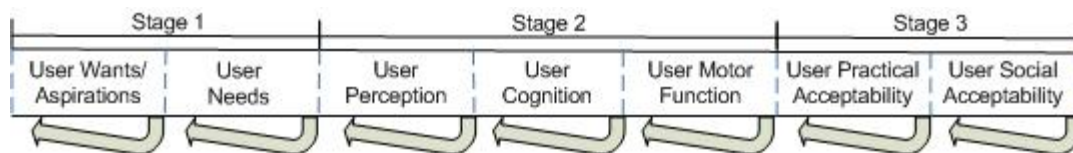


Figure 3.3. 7-level design approach to designing AT from Keates and Clarkston

- Level 1 defines the user needs and the social motivation behind the products.
- Level 2 is focused on defining traditional engineering requirements for the product.
- Level 3 is focused on ensuring that users can perceive information coming to them from the device.
- Level 4 is for matching the behavior of the product with how the users expect it to behave.
- Level 5 focuses on user input into the system.
- Level 6 is an evaluation of the complete device to ensure usability, functionality and appropriateness.
- Level 7 is focused on ensuring social acceptability of the solution.

Between each of the levels is a check/validation step where the evolving design is checked with users to ensure acceptability and may cause iteration if things must be re-worked. These checks not only validate issues surrounding the functionality and user interface of the device, but also other issues of satisfaction, usability, acceptability, utility and social acceptability that are of particular importance in an AT product. If problems or new issues are found, the level can be iterated (indicated by the arrows) until that aspect of the product is satisfactory.

The seven levels generally correspond to what might be referred to as the core part of our generic design process: the Concept, System and Detail design phases. These are the parts of the design process that is most focused on defining and actually creating the product (rather than business, manufacturing or other issues). If these are placed into the generic design process, it would look something like Figure 3.4.

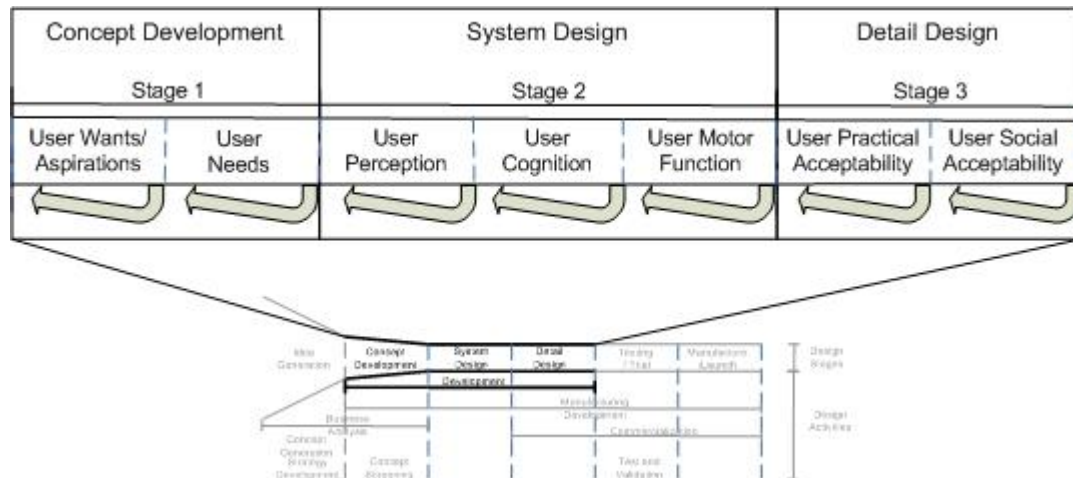


Figure 3.4. Diagram showing how the 7-level approach to inclusive AT design maps to a general design framework

The checks at the end of each level can give designers many opportunities to make sure that all user needs are known and understood. Frequent checks with users allow any necessary changes to the design to be identified and incorporated earlier in the process. Design changes become more time consuming and expensive to implement the later in the process that they are discovered (McGrath, Anthony et al. 1992), so finding and fixing design issues quickly will tend to reduce the overall cost of development. As we have already seen, engaging users so often during each stage can tend to lengthen development time and increase expense. The benefits to the product gained by checking so often with users might be far out weighed by the additional cost and time required to do it.

3.5 Input Timing

At this point we encounter a problem. Design is naturally a very iterative process. It is filled with tasks that are repeated over and over in a process of learning what design approach will provide the best solution for a particular issue. Repeated iterations can potentially lead to better design solutions. In a perfect world, designers would be given all the time they need to find the best possible solution for every aspect of a design.

Unfortunately, task iteration can take up a lot of time during the design process. Iteration drives up the cost of design (affecting the relationship between “good, fast or cheap”). This in turn contributes to higher costs for the finished product and reduces potential profits. On the other hand, some iteration is necessary because the things a designer learns through this process allows better solutions to design problems to be found. If no iteration is allowed non-optimal solutions to design issues are much more likely which affects how good the final product is.

Iteration is necessary in design, but it must be managed. One solution could be to define fewer points in the design process where iteration is acceptable. This is illustrated in Figure 3.5. One advantage to iterating at the beginning or end of a major phase of design has to do with potential input from users. If they are providing input, then they are more likely to be able to give good input at these points. This is because they would be able to view the results of the previous phase, provide input to be used in the next phase and then evaluate the results again at the end of the phase. The benefit to the users is that they are not viewing intermediate results or trial ideas that they might see during the middle of a phase. These intermediate phases could lead them to provide inaccurate input and ultimately be counter-productive.

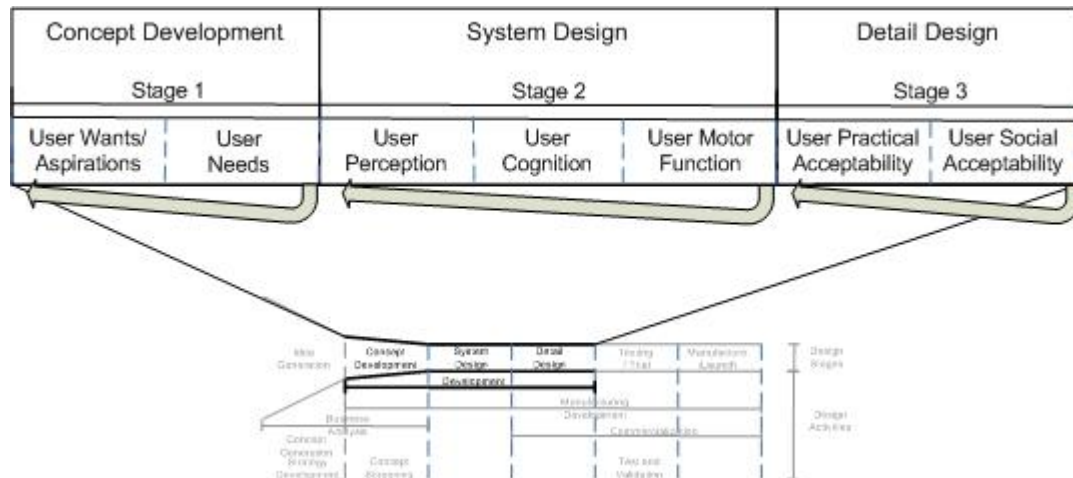


Figure 3.5. The 7-level approach merged with a complete design framework showing how task iteration might be modified better fit in with AT companies

Another approach might be to predict the points during the design process where additional input and potential iteration would be most efficient. This could be done by mapping out all of the tasks that will be required to create the design before starting and using a tool called the Design Structure Matrix (DSM) (Steward 1981) to calculate the ideal points for potential input or iteration. In DSM the tasks for a project are placed into a square matrix with the task names along the left column and top row. This gives each task a unique row along with a column corresponding to all of the other possible tasks. Next, dependencies between tasks are identified by placing a mark in the column that corresponds to the other task or tasks that it depends on. Finally, a process called partitioning reorders the tasks and places them in which they can be most efficiently performed. If any iteration between tasks is required (this happens when two or more tasks depend directly on each other) they form blocks along the diagonal of the matrix which makes dependent tasks easy to identify. These blocks often correlate to functional modules within a design and are points where additional input could be useful. Examples of an un-partitioned and a partitioned DSM can be found in Appendix L. The goal of both of these approaches is to provide the designer with useful information when it is needed as efficiently as possible.

3.6 Input Quality

Now that we can see where input might fit into the design process we can talk about what input actually is. Input, whether it comes from an end user or some other source, is used to learn about the design problem and how specific solutions may be able to solve it. Input is helpful in reducing the User Gap but it can come in a number of forms such as:

- Using tools to simulate a user's perspective (such as the Ford Third Age Suit)
- Getting input from professional therapists
- Observing end users
- Direct, interactive input from end users

Which of these types of input is best? In some cases it may depend on the situation. Recall the example of designing a product for users with dementia who had to be observed because it was not possible to ask directly. However, in general the answer is that nobody really knows for sure because it has never been formally measured (Salvo 2001). All of them are used commonly and certainly appear to be useful but it does not help us to know which would be the best at closing the User Gap.

However, we can surmise that the 'closer' you can get to a user's perspective the more accurate any input will be. The more direct it is, the better it should be. If it is indirect it may be less accurate. This is illustrated in Figure 3.6.

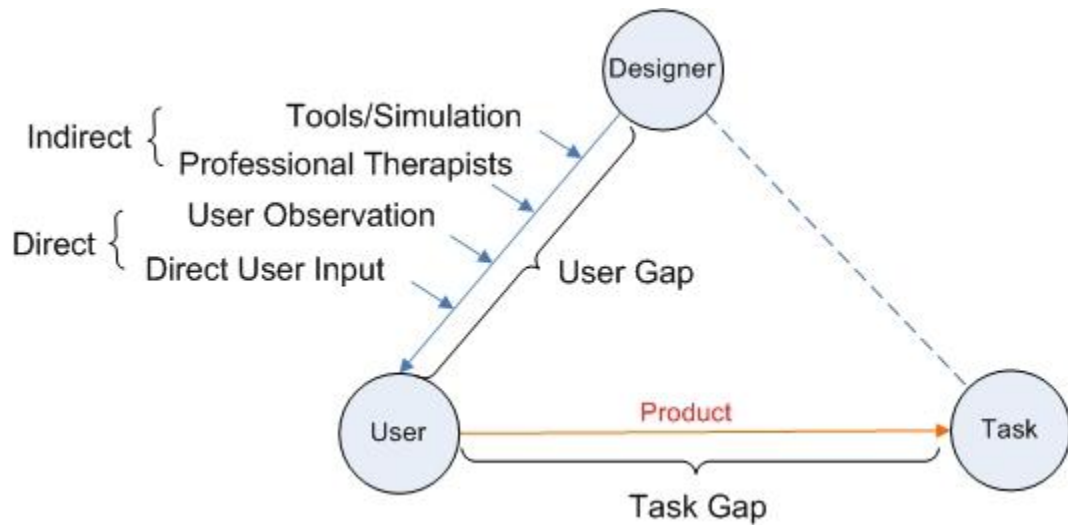


Figure 3.6. Diagram showing how the Task Gap in design may be reduced by using different methods to learn about end users

Each type of input carries its own advantages. Simulation tools have the advantage of being always available for use when input is desired. The input that they provide also does not necessarily require any analysis to be useful because they provide an immediate, first hand experience to the designer. But simulators are the most indirect type of input. Their biggest disadvantage is that the experience that they provide is not necessarily the same in all respect to the condition that they simulate. They cannot provide feedback themselves so there is no way for a designer to know how genuine the experience is that they provide. This lack of accuracy theoretically makes their input less effective.

One of the greatest advantages a professional therapist brings is that a single professional can represent the knowledge and experience of many users. This is because a therapist will work with users with both severe and mild disabilities. They are knowledgeable about problems faces by different users as well as potential solutions of many of these problems and can provide articulate feedback to designers. Yet they are not users themselves and so may not be aware of all problems faced by users and may not place the same importance on some issues as a user might. It is more direct than using a

tool since users are indirectly involved so theoretically will be more effective than tool input.

Observation involves users directly. Designers are able to learn directly from users, however anything that is observed must be interpreted by the designer. It does allow designers to see actual situations that users face and devise potential solutions. Theoretically observation will be more effective than professional input since users are more directly involved.

Finally input from end users is theoretically the most effective of any type of input. It is the most direct and allows users to explain exactly the kinds of problems that they face and why certain problems may be more important to them. It also allows designers to learn about preferences or other issues that may be important but not directly related to a particular design problem.

Input that is gathered during the design process is an important tool to aiding a designer in understanding a design problem. To make a better final product, it is important for designers to get the best information possible during design and that it is obtained in a framework that allows the best use of that information. But out of the different types of input that can aid a designer, which one provides the most bang for the buck?

This is an important question to answer before we can begin investigating possible ways to optimize the design process. Imagine if the perspective that a designer gains while using a simulation tool (like the Third Age Suit) is essentially as good as what could be obtained directly from end users. Using a simulation tool can often be less expensive than going through the process of collecting input from end users. Unlike real users, a tool is something that is generally available to a designer whenever needed. Even if a tool may provide less accurate information about how to solve a design problem, what if the effect it has on the final product turns out to be indistinguishable from a product that gathered input from end users? Given the difficulties and expense of

gathering input from end users, if using a relatively inexpensive tool has about the same impact on the final product, this could have a big impact on the design of AT products. Potentially, designers could focus on gathering input in a way that has the most impact on the final product which would help make the design process more efficient (beneficial to the AT company) and produce better products (beneficial to users). It seems logical that the most useful input can be obtained by getting closer to the end user, but the tradeoff is that input tends to get more difficult/ time consuming/ expensive/ etc as you move toward the user. Because of this relationship, it would be very useful to know how much the final product is affected by each type of input.

3.7 Measuring a Good AT Product

It is unlikely that the User Gap between a designer and user is something that can be measured directly. The goal of input is to give the designer a better perspective of a task. If we want to measure the effect that different types of input have on a product, we are really interested in knowing the effect that a particular type of input had on a user's ability to perform a task with the product. There are three basic categories of factors that we can use to judge how good an AT product is for an end user. They are Effectiveness, Satisfaction and Efficiency.

Effectiveness is simply defined as the accuracy and completeness with which a device achieves the goals for which it was designed. It is commonly measured by the percentage of tasks a user can complete with the product and the number of errors in performing tasks (Mao, Vredenburg et al. 2005; ISO/IEC 2006). Effectiveness is an important measure for an AT product since a product that does not actually work well will not benefit the user. The better that a device is at performing a task, the better it will be in aiding the user. Closely related to this is Efficiency which is the time it takes to perform tasks.

Satisfaction is a little more complex. If an AT product is extremely effective but the user is dis-satisfied and stops using it, then that AT product will not be able to fulfill its goal of aiding the user. In fact, dis-satisfaction is known to be a major cause of device abandonment (Riemer-Reiss and Wacker 2000) so improving satisfaction should be one of the foci of AT design.

Satisfaction can be measured by Ease of Use, Comfort and Safety (Connie and Hershler 1991). For an AT device, satisfaction can also depend on the aesthetics of the device (Hocking 1999; Newell 2003). Users prefer that AT devices are appealing, but they also do not want to use devices that bring unwanted attention (Hocking 1999). Aesthetics affect how the device is perceived not just by the user but also by those around the user. A pleasing device can help improve a user's perception of the device as well as the social acceptability of it, which both contribute to an AT device's satisfaction (Cowan and Turner-Smith 1999; Newell 2003).

From a user's perspective then, AT products can be evaluated and compared by measuring Effectiveness (how well the product solves the problem) and Satisfaction (how easy the product is to use and the likelihood that the user will use it). The components that contribute to these are shown in Figure 3.7.



Figure 3.7. Important measures for evaluating AT products

Different approaches can be used to evaluate outcomes of design. Design can produce a lot of physical artifacts but typically results in three basic forms (Evans 1992):

- Sketches
- Non-Functioning 3-D models (Block models)
- Working prototypes

Sketches could be used, especially if an idea is being evaluated early during development such as during concept development. They can also be useful because they can be produced cheaply and quickly. Non-functioning 3-D models provide better artifacts for evaluation because they allow a user to more clearly see the capabilities and benefits of a product. Users do not have to imagine what the product's form will be like they would with sketches since they can see it, hold it and feel it. They would have to imagine functionality (though it is easier to understand how a 3-D representation of a product might function than it would be to imagine functionality from a sketch). A working prototype allows both functionality and form to be directly evaluated by a user (Page and Rosenbaum 1992).

Based purely on accuracy of the input, user input on mockups or working models is the best. For example, the Australian Bureau of Statistics (ABS) developed a computer support stand for use by their field agents. They based the design on stakeholder input from focus groups and questionnaires. Instead of testing the prototypes, ABS immediately manufactured them for field testing. The initial design was a failure, even though it was designed with user's input. When further testing was done, they found that there were features of the product that users actually disliked, even though they had been requested during the early stages (Green and Jordan 1999). This illustrates what Leonard-Barton describes as user's lack of forward vision (Leonard-Barton 1992) and their inability to accurately visualize a product from an abstract concept. The more

physically real the thing is that users are evaluating, the more accurate their opinions of it will be.

CHAPTER 4

A STUDY OF INPUT DURING AT DESIGN

4.1 Objectives

The objective of this project is project is to document the influence of input on design, to study the impact of user input compared to other types of input to assess the validity of the proposed model that theorizes that the benefit of input type is dependant on its 'closeness' to direct user input. To meet these objectives, three hypotheses are proposed:

H1: Designs resulting from input will embody greater Effectiveness, Satisfaction and Efficiency compared to designs using no input.

H2: Input from end users will result in designs that embody greater Effectiveness, Satisfaction and Efficiency compared to designs using other types of input.

H3: Input that is more directly associated with end users will result in designs that embody greater Effectiveness and Satisfaction than designs using input that is less directly associated with end users.

A study was conducted to test these hypotheses for an Assistive Technology product. The study was divided into two phases, a design phase and an evaluation phase. The design phase involved several teams of designers independently designing a solution for a problem identified by users with limited dexterity. The teams were allowed to utilize a single type of input during the design process. The goal of the design phase was for each team to create a functional prototype and design plans which could then be used to

fabricate a final device. The evaluation phase involved end users using each device to perform a task. Data was collected so that the influence of the input provided during the design of each device could be investigated.

4.2 Measures

Data related to total Usability (Effectiveness + Satisfaction) was collected via an evaluation survey. Data related to efficiency was collected by measuring the time needed to perform a specific task with a device. Devices produced during the study were ranked from best to worst, which was collected via a ranking survey. Several measurements of the level of dexterity limitation were collected from evaluators via survey and various testing apparatus.

4.2.1 Dexterity Measures

Each of the evaluators in the study performed several tests to measure their level of dexterity. The tests ranged from general measurements of upper body function to tests of specific aspects of dexterity. This data was used to document the range of disability represented by the evaluators. It was also used to investigate whether certain types of input had a different effects on device evaluations based on the user's level of dexterity.

4.2.1.1 The DASH

The first measurement of the level of dexterity limitation was taken during the recruitment process. The DASH survey, which stands for Disabilities of the Arm, Shoulder and Hand (<http://www.dash.iwh.on.ca/conditions.htm>), was sent to all potential evaluators to be returned with the other recruitment materials.

The DASH was developed by the Institute for Work and Health and American Academy of Orthopedic Surgeons to provide a quick, self administered measure of symptoms and functional status (Hudak 1996). It is a 30 item survey that asks the taker to rate their ability to perform various activities of daily living. The options for each

include No Difficulty, Mild Difficulty, Moderate Difficulty, Severe Difficulty and Unable. Score on the DASH can range from 0-100 where 0 means a person has no difficulties in performing any of the tasks and 100 means that a person is unable to perform any of the tasks at all.

The DASH comes in two versions: the full 30 item version and the QuickDASH which is made up of 11 items. The questions in the QuickDASH are a subset of the full version. The shorter QuickDASH has been shown to provide similar precision in measuring disability/symptom severity for many upper extremity disorders (Gummesson, Ward 2006). The more sensitive full 30 item version of the DASH was used in this study. This decision was made by testing two users with similar dexterity limitations using the DASH and QuickDASH. The scores between the two users were similar; however since the DASH survey is still relatively short, the decision was made to use the more sensitive full version.

The results of the DASH were used during recruitment ensure that evaluators represented a wide range of dexterity levels. Even though the DASH measures upper body disabilities (not only dexterity issues), it provided a good estimation of a user's abilities.

4.2.1.2 The Nine Hole Peg Test

The nine hole peg test (Mathiowetz et al 1985) (Figure 4.1) is a timed test of finger dexterity and fine motor coordination. It is commonly used by occupational therapists as a quick assessment of finger dexterity (Grice et. al 2003). The test consists of measuring the time it takes to place 9 dowels into 9 holes on a board and then remove them. The test taker removes the pegs from a container one at a time and places them in the board from right to left starting from the top. Once all the pegs are placed, they are then removed (in any order) and placed back into the container. The time is measured from when the test taker touches the first peg in the container to when the final peg is put back into the container.

The nine hole peg test used in this study was a home made version following the original specifications. It consisted of 9 wooden dowels each 9mm in diameter and 32 mm long. The wooden base had 9 holes each 10mm in diameter and 15mm deep. The holes were spaced 15mm apart with three rows of holes. The container for the pegs was 100mm square with sides 100mm deep. Results from the nine hole peg test were used to investigate whether evaluations of the study devices differed based on the user's level of finger dexterity and fine motor coordination.



Figure 4.1. Nine-Hole Peg Test apparatus used in the study

4.2.1.3 Pinch and Grip Strength

Pinch and grip strength were measured for each participant in the study. This was done using a Jamar dynamometer (Figure 4.2), which has been shown to give the most accurate measurement of grip strength (Mathiowetz 1984). Six measurements were taken of participant's grip strength: three of the dominant hand and three of the non dominant hand. The measurements were taken with the participant seated with the arm held at a 90 degree angle. This position was chosen as it has been shown to be highly repeatable (Hillman et. al 2004).

Pinch strength was measured by taking two types of measurements. One measure was the ‘tip pinch’ in which the user pinches using the tip of the thumb to the tip of the index finger. The other measure used was the ‘key pinch’ where the thumb pad is pressed to the lateral aspect of the middle phalanx of the index finger (Mathiowetz 1984). Six measurements of each type of pinch were taken (three measurements from the dominant and three from the non-dominant hand). The mean values of the pinch and grip tests for each hand were used to investigate whether user evaluations differed based on their performance in these tests.



Figure 4.2. Devices used to measure grip strength (top), ‘tip pinch’ strength (bottom left) and ‘key pinch’ strength (bottom right)

4.2.2 Evaluation Survey

A Likert item survey was developed to measure evaluators’ opinion of the level of effectiveness and their level of satisfaction with the devices. The measurement of a Likert survey is based on the premise that responses to many questions that reflect the variable under consideration will provide a reasonable measurement of that variable

(Babbie 1990). The evaluation survey (Appendix I) in this study contained a total of 12 questions related to effectiveness and satisfaction. Each survey question had 5 possible answers that were scored as follows:

- 1 = Strongly Disagree
- 2 = Somewhat Disagree
- 3 = Neither Agree nor Disagree
- 4 = Somewhat Agree
- 5 = Strongly Agree

Some of the survey questions were related aspects of effectiveness and other questions were related to satisfaction of a device. A score representing an evaluator's opinion of effectiveness could be obtained by adding the values of all of the satisfaction related survey questions. The Effectiveness score was calculated by summing scores for questions 1, 2, 9 and 11 on the evaluation survey. The Satisfaction score for a product was calculated by summing scores for questions 3, 4, 5, 6, 7, 8, 10 and 12 on the evaluation survey. The total score of the 12 Likert items reflected an evaluator's opinion of the overall usability of a device. A 13th non-Likert item question was asked the evaluator to provide a single answer about the evaluator's overall opinion immediately after using the device. The answers to this question were scored from 5 (the top answer) down to 1 (the bottom answer). The question was:

Please mark the statement that most closely matches your overall opinion of the product:

- () The product is very good, I like almost everything about it.
- () The product is mostly good and there are only a few things about it that I don't like.
- () The product is average, there are about as many things that I like as dislike
- () The product is mostly bad, I liked some aspects, but I disliked most things about it
- () The product is bad, I did not like anything about it

The evaluation survey was tested initially to ensure that the wording was understandable. Once the final wording was established, Cronbach's alpha coefficient (Carmines and Zeller 1979) was calculated for the evaluation survey to measure internal consistency reliability (Gilem and Gilem 2003). To do this, a second survey (Appendix R) was created that asked the same questions using different wording to test Cronbach's alpha. Five different users evaluated one of the study devices by using the device and filling out both surveys. The results from both were used to determine that Cronbach's alpha coefficient for the study survey was .903. Cronbach's alpha has a maximum value of 1 and it is widely accepted that values should be greater than .70 before a survey is used.

4.2.3 Ranking Survey

After using each of the devices, the evaluators ranked each of the study devices in order from best to worst (the standard tape dispenser was not ranked). The evaluator was given a survey showed pictures of all 8 of the study products from top to bottom with a line in front of each. The evaluator then filled in the number (1 for best and 8 for worst) next to each product in the order that they preferred them. The device ranking survey can be found in Appendix U. All of the procedures followed during the evaluations and the instructions given to the evaluators can be found in Appendix K.

4.3 Subjects

4.3.1 Designer Recruitment

Student designers were recruited via fliers and email (Appendix D). Interested students were required to:

- be a junior or senior undergraduate student in Industrial Design
- have achieved a grade of A or B in the previous semester design studio class

Junior and senior students were used to ensure that all participants had acquired all of the skills necessary for the project through their normal coursework. The studio grade was used as an objective measure of a student's design abilities. While there is variability between an A and a B student, the majority of students in this range should be similarly capable of performing the design tasks. Even if a 'skills test' were administered to each participant there would be no guarantee that it would be more accurate than the studio grade.

Students were excluded if:

- they had ever taken part in the design of an AT product outside of their normal course of study
- they had experience with using AT products
- they personally had a functional limitation
- they had a family member or a close personal friend with a disability

The exclusions were made to ensure that each designer had the same level of exposure to issues related to assistive technology and disability. If one designer had more personal experience with these issues than another, it could potentially provide them an advantage in designing AT solutions. Since the effect that this experience could have on the designer's ability cannot be measured or accounted for, they were excluded to eliminate the potential difference. All interested students completed a screening survey (Appendix E) to determine their level of personal experience with AT issues.

Each student participant signed an informed consent form approved by the Georgia Tech Institutional Review Board. Consent was obtained before beginning any study activities. Each design team member was compensated \$224 for completing the study. The students were organized into design teams, each of which received \$60 on the first day of the design phase to cover the cost of materials.

4.3.2 Evaluator Recruitment

Twenty (20) users with dexterity limitations were recruited to perform device evaluations. Potential evaluators were eligible to participate if they:

- were aged 18 years or older
- had a dexterity limitation (defined as reduced ability in grasping, holding, squeezing or fine finger manipulation)
- were in the Atlanta area
- did not have a sensory limitation (i.e. hearing or vision)

Evaluators were primarily recruited via email through the CATEA (Center for Assistive Technology and Environmental Access) Consumer Network (CCN). The CCN is a network of older adults and people with disabilities whose members test new prototypes, products and services in order to improve them through focus groups, field-testing and surveys (<http://www.catea.gatech.edu/ccn/ccn.php>). Invitations to participate were also sent to many additional organizations in the Atlanta area. A complete list can be found in Appendix T. The fliers and screening materials used during recruitment can be found in Appendix O.

Each evaluator signed an informed consent form approved by the Georgia Tech Institutional Review Board. Consent was obtained before beginning any study activities. Each evaluator was compensated \$60 for completing the device evaluations. Evaluators were also provided an optional media release form to allow pictures taken of them during the study to be published.

4.3.3 Stakeholder Recruitment

A group of stakeholders were recruited to provide input to the designers during the design phase of the study. The stakeholders included end users with dexterity limitations and an occupational therapist (OT) who provided the user input and professional input respectively.

Three people with dexterity limitations were recruited so that they covered a range of different abilities. Overall one user had a more severe dexterity limitation, one had a less severe limitation and the third was about in the middle. Some specific details about each of the users:

- One user had a stroke three years earlier. The result of the stroke was a permanent tremor and weakness in the user's left side.
- One user had a C5/6 incomplete spinal cord injury 37 years earlier. More than 30 years of practice allowed the user to find ways to compensate for loss of hand function. The user's thumb and index fingers function on both hands with a little more function in the right hand but fine motor function is still problematic.
- One user was born with spastic cerebral palsy. This muscle movements of the condition cause individualized fine motor movements to be translated into gross motor movements involving more than one muscle group.

The professional input was provided by an OT with experience working with users with limited dexterity. Previous experience was important to ensure familiarity with the needs and problems faced by users with limited dexterity so that the design team could learn from this knowledge during design. All of the stakeholders, both users and professional, signed informed consent forms before participating in study activities.

4.4 Procedures

4.4.1 Design Phase

4.4.1.1 The Design Task

An ideal design problem for this study would be one that is relatively simple so that a product can be designed for it quickly. The problem could not be so simple that there were only a few obvious design solutions. If the problem was too simple, different individual design teams would be more likely to come up with very similar solutions regardless of the type of user input that was given to them. This situation would make it hard (or impossible) to tell what impact different types of input during the design process actually had on the product. At the same time, the design problem could not be too complex. A problem that was too complex would make designing a successful solution in a relatively short period of time difficult. Increased complexity could also lead to too many potential solutions. In this case, the resulting designs could be very dis-similar and not comparable with each other.

Since we are interested in AT design specifically, the design task also needed to be one that addressed a real need of users with a disability. After some brainstorming, the focus chosen for the design task were employment environment related problems encountered by people with limited dexterity. The specific disability chosen did not matter, however it was important to choose one for which an appropriate design task could be identified. It also needed to be one that end users could be recruited and participate fully in the study activities.

To identify a specific design task for study, a focus group of users with limitations in dexterity was recruited to discuss problems that they have encountered with work related tasks. Three potential tasks were pre-selected for discussion and a ‘brainstorming’ time was built into the focus group session to allow the group to discuss ideas from their own

experience that might be relevant as a design problem for the study. The recruitment materials, the discussion script that was followed during the focus group, the tasks performed during the discussion group and detailed results of this focus group can be found in Appendix A.

Based on the focus group, the best candidate task for this study was determined to be the task of taping a box. The focus group identified many problems related to performing this task which indicated a good possibility that there would be many different ways of solving the problem. The focus group results also indicated that the task itself was relatively simple, so generating a design solution for it in a relatively short time was possible. Needs and requirements for taping a box were gathered from the focus group and used to generate a design brief (Appendix B) that outlined the basic requirements of the design problem.

4.4.1.2 Design Teams

The student designers were organized into teams of two. A design team approach, rather than a single designer, was chosen for the study for a number of reasons:

- Teams with more than one member can be balanced with respect to one another
- Design in the real world is most often performed in teams
- Some designers will be better at certain tasks than others. Some may have great prototyping skill while others are better at engaging users. A team with more than one designer helps ensure that the team has all of the skills necessary (at a good level) to perform all of the required design tasks
- A team allows the design workload to be shared
- Students have schedules and obligations (such as classes). Having more than one member would allow the team to work around individual conflicts and continue design work

The skills and abilities of designers are directly related to the amount of experience that they have doing design, so a designer's level of skill could have a large influence on the study results. Experienced designers are significantly better at assimilating information and translating that information into potential solutions (Crismond 2001). The variability of skill between different experienced designers would be impossible to measure and would confound the results since it would not be clear if differences between designs were due to the effect of input designer experience. Novice designers with very similar experiences gained through their studies were chosen to eliminate as much of the unknown experience factor as possible. Of course there are variations between individuals, but it is small compared to the differences between expert designers who may have years of differing real world experience.

Each design team was made up of one junior and one senior student. Since there are always differences between individuals (their personality, creativeness, etc), the junior and senior member was assigned to each team randomly to help ensure that the design teams were as equivalent as possible. This was done by writing the names of each participant on a slip of paper and placing the names of all of the junior students a hat and the names of the senior students in another hat. There was also a third hat that had slips of paper with the names of each design team (ie, 'user input team 1', 'user input team 2', 'tool/simulation team 1', etc). To choose the team members, a team name was drawn out of the team hat, next a senior student was pulled out of the senior hat and then a junior student was pulled out of the junior hat. Balanced teams should ideally produce equivalent designs if given the same inputs.

4.4.1.3 Design Process

A total of 8 design teams performed the design task with each team receiving only one type of input during the design process as shown in Table 4.1.

Table 4.1. Types of input that each team received during the design process

		Design Team							
		1	2	3	4	5	6	7	8
Input Provided	None	x	x						
	Tool/Simulation			x	x				
	Professional (OT)					x	x		
	Direct User Input							x	x

The design process was divided into three stages: Concept, System, and Detail design to correspond to when the details of a design solution are devised and implemented during the generic design process. The three design phases ran one after another with no delay between. This was to ensure that each team was given the same amount of time for design regardless of the type of input they received. The schedule for each design phase was:

- Concept design. Duration, one 4 hour session.
- System design. Duration, 5 days (recommended 2 hours/day).
- Detail design. Duration, 5 days (recommended 2 hours/day).

Except for the initial four hour concept design phase that was performed in a single session at CATEA, each team set up their own times to work on design tasks for the study. This allowed participants to fit the study into their schedules. It also allowed each team to spend the time needed to complete design tasks since individual designers work

at different speeds and because different concepts may require more or less time to complete than others. The end of each phase was a hard deadline which no team was allowed to work past.

Each design team was responsible for producing deliverables at the end of each phase. The deliverables and schedule (Figure 4.3) were outlined in the design brief given to each team.

- Concept Design Deliverables - Each team was responsible for turning in sketches and plans for their concept at the end of the concept design session.
- System Design Deliverables- Each team was responsible for turning in a basic functional prototype (this consisted of demonstrating it to study staff) anytime before midnight of the last day of system design.
- Detail Design Deliverables- Each team was responsible for turning in technical drawings and detailed descriptions of their design along with the final prototype before midnight of the final day.

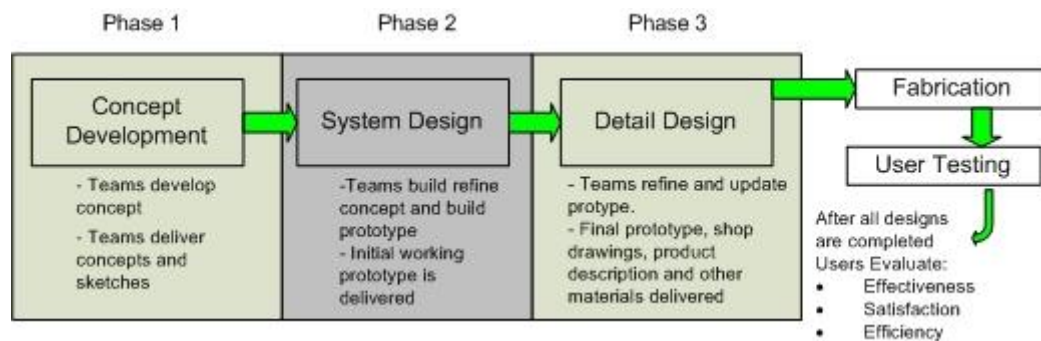


Figure 4.3: Study schedule and major deliverables from design teams

The deliverables served as a mechanism to ensure each team stayed on track. This was particularly important for teams that received input from users or from the OT. The deliverables ensured that the teams created realistic (as much as possible) prototypes so

that input on the evolving design from stakeholders (users and OT) was as accurate as possible.

4.4.1.4 Design Input

Each team was given the same design brief and a packet of basic information about dexterity limitations (Appendix C) at the beginning of concept design. For the control team (None), these documents were the only ‘input’ that was provided.

Teams using simulation tools were given a set of identical tools to use and were allowed to keep them through the entire duration of the study. This was done because one of the advantages of a simulation tool in the real world is that is generally available whenever it is needed by the designer. A glove resembling an oven mitt, a leather work glove and a specially constructed glove were used for the simulation tools (Figure 4.4). The special glove was based on a similar glove originally developed at the University of Cambridge (Goodman and Waller 2007). It is basically a standard leather work glove with plastic strips sewn on so that they extend over the tops of the fingers which make it more difficult to bend the fingers. Velcro loops on the tips of the fingers reduce the ability to perform fine finger. The loops also allow the plastic strip to be released from individual fingers, if desired, so that finger movement is less restricted.



Figure 4.4: Simulation tools used in the study. Top row: Dexterity simulation glove based on University of Cambridge design. Bottom left: Oven mitt like dexterity simulator. Bottom Right: Leather gloves for limiting dexterity

Teams receiving input from stakeholders (users or the OT) were given input at three specific times during the design process for set durations (Figure 4.5):

- The stakeholders joined the design team during the entire concept design session. This was provided during the entire sessions because concept design is the phase where designers examine the problem and devise possible solutions. Input is typical during this phase to aid in this process and to help a design team in selecting a good concept solution.
- A 2 hour input session with the stakeholders was provided on the first day of detail design. Input is commonly used during detail design to allow designers to revise their concept and fix any problems that may not have been addressed in the previous design phase.
- A 2 hour input session was provided on day 3 of detail design. This was done to give the stakeholders a chance to evaluate the results of their previous input session and recommend any final changes to the design.

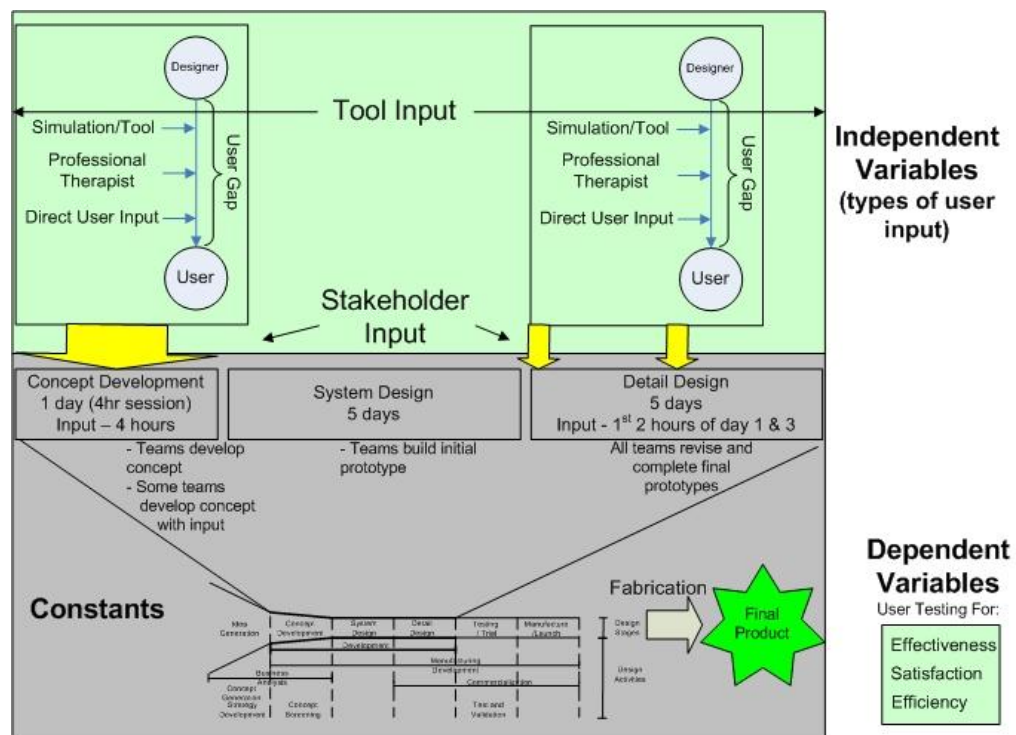


Figure 4.5: Overview of the study showing the phases of the generic design process that were performed and timing of input

Each design team performed the study independently and had no interaction with other teams. Each team was assigned to work on activities for the study in a physically separate shop on the campus of Georgia Tech. The design teams were not allowed to perform any external research to aid in their design task. This included talking with others about the study or utilizing the library or the internet. The teams were only allowed to use the materials on dexterity given to them (Appendix C) along with the type of input allowed to the team. Normally a designer would have these resources available but the restriction was necessary in this case. Since the object was to measure the effect of specific input, if a design team performed additional research, the things they learned from this would be indistinguishable from what they learned about the problem through the input. All of the materials and procedures were pilot tested before beginning the design phase. Results from the pilot can be found in Appendix J. An overview of the actual study schedule showing the dates and locations that each team performed design work for the study can be found in Appendix H.

4.4.1.5 Instructions to Design Teams

Each team was given a document of instructions before beginning the design task. This document contained some background information about the study and its purpose along with the procedures that each team was required to follow for the study. These instructions were very important in helping to control possible confounding factors in the study since it was unlikely that designing and building a design prototype could be done over just one or two days. Since it would also not be possible to isolate the students for the project, it was important to make sure that the participants understood and followed the requirements and restrictions of the study. The instructions outlined for each team things that they were and were not allowed to do during the study. The instructions given to each team can be reviewed in Appendix F.

4.4.1.6 Instructions to Stakeholders

The same group of stakeholders was used to provide all of the user input throughout the study. This was done to provide some control over the content of the input supplied to the design teams. If one group of stakeholders supplied input to one team and a different group supplied input to a second team, it would be difficult to know if the product produced by one team was better or worse than the other team was because the input from the users was simply better than the other. Using the same stakeholders ensured that the ideas, opinions and experiences of the group were constant even though the content of specific discussions with different designers could be different.

Some additional instructions were given to all stakeholders before beginning the study since they would be providing input to more than one team. They were instructed to allow the design teams to take the lead with design ideas to help prevent them from ‘contaminating’ the design teams with the same ideas. Stakeholders were allowed to give any kind of information to the design teams about ideas that the designers developed. They were encouraged to tell the design teams whether they liked ideas or not as well as specifically what was good or bad about them. The idea was to let the designers lead the process of investigating the design problem but to ensure that the stakeholders helped to lead the designers to better solutions based on their input. The instructions given to the users can be found in Appendix M and those given to the OT can be found in Appendix N.

4.4.1.7 Design Fabrication

The design team submitted prototypes, technical shop drawings and product descriptions sent to a single fabricator. A single person was used for fabrication to ensure that the quality of all of the devices was consistent. Fabrication of the designs was undertaken because it was expected that the design team prototypes would vary greatly in quality (which proved to be true). If they had been used, the evaluations would almost certainly have been affected by these differences.

4.4.2 Evaluation Phase

Each of the evaluators independently evaluated each of the devices produced during the design phase. The evaluation sessions were divided into three basic parts:

- First – Measurement of the user’s level of dexterity limitation
- Second – Evaluation of each of the products (performing a task with the device and completing the evaluation survey)
- Third – Ranking the products in order from best to worst

A standard sized box was pre-loaded and placed next to each device. The load in each box consisted of a ream of printer paper and packing peanuts to fill the remaining space. The load was chosen so that it would be of medium weight so that the boxes could potentially slide on a tabletop but would not slide if bumped casually. Enough packing peanuts were added to each box so that the flaps of the boxes would fold down to a flat surface (i.e. didn’t bulge out) and would not cave in when pressed. The box used for each product was 12in x 12in x 12in which corresponded to the middle range of the specification outlined in the design brief. The box was also tested to verify that it worked with all of the products to ensure that each could be evaluated successfully. The process used to select the size and weight can be found in Appendix P.

The evaluation task was to tape closed a box with each of the devices. The participants were instructed to close the box so that the top flaps provided a single line to be taped. Each product was used to place a single strip of tape placed along the top flaps and going slightly (a few inches) over each side. The task was timed from the moment the evaluator touched the device to begin closing the box to the moment that sealing the box was completed. This method was used so that there would be a consistent, reliable way of knowing when to start and stop timing so that all of the timing measurements are actually of the same thing.

A total of 5 minutes was allowed for the user to complete the task from the moment they began. 5 minutes was chosen as a maximum time based on a pilot test of the evaluation procedures (Appendix Q). The evaluator was allowed to give up on the task if they felt that it could not be accomplished. The evaluator was allowed to re-try the task after starting (but before finishing) until they completed or gave up on the task. 5 minutes was still allowed for a re-try. If an evaluator gave up, this was recorded and a value of 5 minutes was entered for the task duration. After completing the task (or giving up) with a product, the evaluator completed the evaluation survey.

A standard tape dispenser was the first device used by each evaluator. It was evaluated since the devices designed in the study would ideally replace it for the task that the participants performed. It provided participants a point of reference for comparing how well study products performed in comparison. After the standard tape dispenser, the order of the study devices was randomized. The order was determined before the product evaluation began by placing all of the product names into a hat, mixing them up and drawing them out one by one. The final script that was followed to guide the evaluator through each step of the evaluation can be found in Appendix S.

4.4.3 Analysis Methods

Hypothesis testing was conducted using the Mann-Whitney and Kruskal-Wallis Tests. The Mann-Whitney (or Mann-Whitney U) test is a non-parametric test to determine if two independent samples of observations come from the same distribution (Mann and Whitney 1947). The test involves the calculation of ranks to determine significant differences between groups (Siegel 1956). The Kruskal-Wallis test is an extension to the Mann-Whitney test uses ranks to determine differences between three or more groups. It is equivalent to a one way analysis of variance except that the data is replaced by the ranks (Kruskal and Wallis 1952). These tests were chosen because of the ordinal nature

of the survey data. They are also appropriate for use with interval or ratio data that is not normally distributed (Knapp 1990), (Jamieson 2004).

CHAPTER 5

DESIGN STUDY RESULTS

Each of the eight design teams successfully created a product prototype during the design phase of the study. Each of the products was fabricated based on the designers' prototypes, shop drawings and descriptions of how the product should work and how users interact with it. Before presenting the evaluation results, each of the products will be presented with a brief description of how the design team intended for the product to work and any differences introduced by the fabrication step. Since some teams were unable to fully describe how the mechanics of some product features should be built, some differences from the designer specification arose out of the need to implement the functionality and interaction between the user and the product. Each product was given a name that to refer to it during the study and are used in the discussion that follows.

5.1 Products Produced with Direct User Input

5.1.1 User Input Team 1: Tape Stamper Product



Figure 5.1. Tape Stamper product designed with input from end users



Figure 5.2. Tape stamper product in use

The tape stamper product (Figure 5.1 and Figure 5.2), designed with direct input from end users, is made up of two parts: a dispenser unit and a storage/stabilization unit. The storage unit is a plastic container made up of two halves that nest on top of each other hold the dispenser unit and the charging platform for the dispenser when they are not in use. The halves can also be used to help hold a box steady while being loaded or taped. The top and bottom of the storage unit are covered with a rubberized material to help prevent them from slipping. Each half also has a flat triangular extension that can be used to wedge a box in place from opposite sides.

The stamper unit is a hand-held device with a Velcro strap and button on the top that can be used with one hand. The device can be held by the strap or a hand can be placed under the strap so that the device hangs from the hand. A button switch on the side is used to turn the stamper on or off. Once turned on, the stamper can be placed directly on the location where tape should be dispensed. The tape is ‘stamped’ onto the

box when the button on the top is pressed. A clear window on the side of the dispenser shows how much tape is left on the roll. The panel can be easily removed by pulling on a small handle just above the window to allow the tape to be replaced. The dispenser is wireless and is re-charged when placed on the charging pad when not in use. The pad uses induction to charge the battery in the same way that some cordless toothbrushes are re-charged.

There were a few differences between the final fabricated version and the descriptions provided by the design team. The largest problem encountered by the fabricator was how to devise a mechanism that was capable of feeding a defined length of tape, cutting it, and then pressing it straight down without becoming jammed. Several of these problems were solved by using label rolls in place of a roll of tape. Jamming problems were eliminated since the sticky side of the labels are covered with a backing. The use of labels also allowed a mechanism to be built that easily separated the label from the backing. This left the issue of how to press the label directly downward. This problem was never completely solved and resulted in the need for a user to slide the stamper across the targeted location on the box.

This change in interaction between the user and the product seemed to make it somewhat more difficult to use. The intended usage of the device (that it should press tape straight down) was described when the usage of the product was explained. The users were asked to simulate using the device ‘properly’ during the practice time to get a feel for how it might feel to use it as it was designed. This simulation was simply having the user hold the device, place it on the box where they might want to tape and pressing the button. The power was turned off (so no label was dispensed) so that it would not jam.

A number of users came up with alternate methods for using the device during their practice time with it. This would have happened despite the difference from the designed function. For example, some users simply did not like having the device strapped to their

hand. The users were asked if their opinion of the product would be different if it were able to function as the designers planned. Interestingly, none of the users felt that it would have made a difference. It was not an issue for users who liked the device. For users who disliked it, the reasons they cited were all related to other things. The most common reasons it was not liked were due to the device's shape, weight and that they did not like the 'stamping' motion for applying the tape.

The fabricated prototype was not easily re-loadable. The stamper was designed so that the side could be pulled off to give easy access to the tape inside. The side could be removed in the fabricated version, however the internal motor blocked access to the tape. Reloading the fabricated version required the removal of several screws at the bottom of the device (where the tape comes out) so that the internal mechanisms could be removed from the external housing. The device was not re-loaded by users as part of the evaluation.

The fabricated stamper was powered by conventional battery. A fake charger was built to represent the inductive charging pad envisioned by the design team. There was also one aesthetic difference in the fabricated stamper. The design described the viewing window on the side as long and vertical. The viewing window on the side of the fabricated stamper was oriented horizontally and was more rectangular.

Finally, this team had two challenges that no other team in the study experienced. The first is that one of the team members was forced to withdraw for personal reasons. Both of the design team members were able to participate together in all of the user input sessions and were able to make the major design decisions about the product before the withdrawal. The remaining team member had a strong desire to complete the study and did not feel the loss of the other team member would be a problem considering the state of the design plan at that time. The second challenge is that the remaining team member had a minor shop accident on the final day of detail design but completed the final prototype and study deliverables on time despite the added delay.

5.1.2 User Input Team 2: Automated Tape Feeder Product



Figure 5.3. Automated Tape Feeder product designed with input from end users



Figure 5.4. Automated Tape Feeder product in use

The automated tape feeder product (Figure 5.3 and Figure 5.4), designed with input from end users, is made up of two components: a dispenser unit and an easel for box stabilization. The easel is designed to sit on any flat surface and can be adjusted to tilt the box at three different angles. One side of the box is held in place with a slider that slides in and out to fit the width of the box. The slider can be placed into either the left or right side of the easel to better suit right or left handed users. The easel can be laid flat for storage and can be carried using a handle integrated into the base. All of the adjustment handles were designed so that they can be used with one hand. Icon based instructions on using and adjusting the easel are printed on the top surface.

The dispenser unit is designed to sit on the edge of a table and dispense tape in three inch increments by pressing a green outlined 'Dispense' button on the top part of the unit. When the desired length of tape has been dispensed, it is cut free by pressing a red outlined 'Cut' button on the front of the unit. The dispenser has a small lip that extends down on the front of the device. The lip provides an opening for the tape to come out and also prevents the unit from sliding away from the user when the dispense button is pressed. After the tape is cut, the user can then place it on the desired area of the box.

There were a few differences between the designer prototype and fabricated versions of this product. The description provided by the design team described that a single press of the dispense button would feed out a measured three inches of tape at a time. The fabricated version required the user to keep the dispense button pressed and simply dispensed tape while the button was pressed.

The dispenser was also originally intended to dispense standard tape. This problem was similar to the tape stamper since it is difficult for an internal mechanism to pull tape off a roll and push it outside of a device without sticking and jamming. This problem was resolved by using clear contact paper that was cut into rolls about an inch and a half wide. The backing that covers the sticky side of the contact paper resolved the potential

jamming problem. The backing was removed within the dispenser so that the sticky side was exposed on the dispensed strip, just like a strip of tape would be.

Finally, designers had specified that all parts of the easel, except for the base, would be made out of aluminum. The intent was to make it light yet durable. The fabricated easel was made from plastic that was painted an aluminum color. While the visual appearance was similar, the top part that the box sits on was heavier than it would have been otherwise.

5.2 Products Produced with input from an Occupational Therapist (OT)

5.2.1 OT Input Team 1: Powered Pole Product



Figure 5.5. Powered Pole product designed with input from an OT



Figure 5.6. Powered Pole product in use

The powered pole product (Figure 5.5 and Figure 5.6), designed with input from an occupational therapist, is designed to help remove much of the manual work of closing box. It is made up of a 'shelf' that travels up and down a pole and can be rotated to the left or right. The shelf can be adjusted to the height of a box that needs to be closed. The shelf contains a pair of 'arms' that hold down the flaps on a box. The arms are powered and can be extended and retracted as needed. A tape dispenser unit is located on the top of the shelf and is attached to manual telescoping arms. A cutting blade is located on bottom, rear corner of the tape dispenser. The dispenser can be rotated on the end of the arms to allow the blade to cut the tape.

All of the powered operations can be controlled from the foot buttons on the base of the device. From left to right, the buttons allow the user to move the shelf up the pole, move the shelf down the pole, rotate the shelf clockwise, rotate the shelf counter-clockwise, pull the box-holding arms into the shelf, and extend the box holding arms from the shelf. Locking casters are affixed to the bottom of the device to allow it to be easily rolled to a box. Once the box is packed, the user can roll the device to the box, position the taping shelf by using the foot controls, hold down the box flaps by extending the arms and lowering the shelf, and finally the tape can be affixed to the top by affixing the exposed part of the tape to the side of the box and pulling the dispenser over the top.

The fabricated version of the pole product was very close to the description provided by the design team. One difference is that the designers indicated that the central pole would be a silver color. On the fabricated version it was white. In the fabricated product, a number of control wires were exposed coming out of the shelf. It was not described this way by the designers. With the timeline allowed for fabrication it was not possible to devise a way to reliably control the shelf while hiding these from view.

5.2.2 OT Input Team 2: Wall Mounted Product



Figure 5.7. Wall Mounted product designed with input from an OT



Figure 5.8. Wall Mounted product in use

The ‘wall mounted product’ (Figure 5.7 and Figure 5.8), designed with input from an occupational therapist, is designed as a packing station and can be used with one hand. The product consists of a tape dispenser which is mounted on a series of tracks. A tape dispenser is attached to a ‘dispenser track’ and slides back and forth so that it can be

aligned with a box. The dispenser track is attached to a pivot point on a vertical track. When now in use the dispenser folds down and rests flat against the wall. When in use, the dispenser track can be rotated up so that it is horizontal and can slide up and down to align with the top of a box. The vertical track is part of a third track which rolls back and forth along the wall. Once aligned the beginning of the tape is affixed to the box and the dispenser is pushed over the top of the box. A cutting blade is located just on the back side of the dispenser (slightly toward the user). When the dispenser reaches the back edge of the box, it naturally slides down, which brings the blade in contact with the tape and cuts it. The box itself is held in place by an arm that pivots out to form a corner on the back side of the box.

The fabricated version of the wall mounted product was very close to the description provided by the design team. The main difference is that in the original design, there was a cam on the pivot point where the dispenser track was attached to the vertical track. The cam was placed there to prevent the arm from crashing suddenly into the vertical track if it was let go by the user. When the fabricated version was completed, it was discovered that the cam would run into the top inside corner of the box. This dented the corner of the box and caused damage and prevented the dispenser from being drawn across the top. Removing the cam eliminated this problem without changing the interaction with the end user. There were not any issues during evaluation with the taping track crashing into the wall if it was dropped.

5.3 Products Produced with input from Tools

5.3.1 Tool Input Team 1: Table Mounted Product



Figure 5.9. Table Mounted product designed with input from simulation tools



Figure 5.10. Table Mounted product in use

The 'table mounted product' (Figure 5.9 and Figure 5.10), designed with input from simulation tools, is actually several items designed to work together. First is the tape dispenser component. This consists of a dispenser on top of a telescoping pole that is meant to be mounted on a table or workspace as desired. The dispenser features a dowel like extension used to hold down the box flap on the far side of the user. To tape a box, a user would only need one hand. The dispenser features a low cutout that allows a user to put a hand under the tape so that it sticks to the top of the hand. This is useful for users who are unable to grasp or have low fine motor skills. A user can then lift up and pull the tape across the top of the box. The user's arm will naturally hold down the box flap nearest to them. The tape is placed on the far edge of the box with a downward motion. This motion also helps the user to unstick the tape from their hand. Finally, the strip of tape is pressed down against the box, starting from the side farthest from the dispenser. The top edge of the dispenser is a cutting blade and as the tape is smoothed down, tension builds up on the tape strip until it is cut.

The other items that make up the product are a backstop and a rubberized mat. The backstop helps prevent the box from sliding too close to the dispenser while being taped and ensures that when the tape is cut, there is enough of a tail to be folded over the edge of the box. The rubberized mat also helps prevent the box from sliding. The mat also has a yellow line which corresponds to where the center of the tape from the dispenser will fall. This is used to properly line up the box before taping.

The fabricated setup of this product was different from the designer description in one way. The designers described that the dispenser would be mounted on a table with two feet from either side of the center line on the rubberized pad to the edge of the table. It was originally built to this description but the distance between the edge of the table to the dispenser made the tape very difficult to reach. Since the product was also described as several components that would be setup to meet the end user needs, the width of the rubberized surface was reduced by half so that it was only one foot from the center line to

either edge. This made the dispenser easily accessible from either side and would still be able to hold the maximum sized box specified in the design brief.

5.3.2 Tool Input Team 2: Cabinet Mounted Product



Figure 5.11. Cabinet Mounted product designed with input from simulation tools



Figure 5.12. Cabinet Mounted product in use

The ‘cabinet mounted product’ (Figure 5.11 and Figure 5.12), designed with input from simulation tools, is designed as a tape dispenser that is mounted under a cabinet or shelves to provide a taping station. The dispenser is attached to a pair of telescoping arms. The arms allow the dispenser to swing back and forth. The dispenser is swung up and the handle is attached to a hook that is placed in the front of the cabinet to help keep

it out of the way when not in use. The handle is made from a soft but durable foam-like material. To use the dispenser, a box is placed on the table surface and packed. When the dispenser is unhooked, it hangs vertically from the bottom of the cabinet. The height of the dispenser is unhooked, it hangs vertically from the bottom of the cabinet. The height of the dispenser is adjusted by simply pulling up or down using the handle. The telescoping arms are attached to a track on the bottom of the cabinet that allows the user to slide the entire mechanism from front to back. Tape is applied to the box by sliding the box across the table surface under the dispenser. Once the height and position have been adjusted by the user, the leading edge of the tape is attached to the front of the box and the box is pushed. A curved plastic guide presses the tape down onto the box as it passes under. A cutting blade is attached to the rear edge of the plastic guide. The tape is cut by pulling the device downward after the box has passed under the dispenser. The only difference from the designer description is that in the fabricated product the curved plastic guides were slightly shorter.

5.4 Products Produced with No Additional Input

5.4.1 None Team 1: Tape Puller Product



Figure 5.13. Tape Puller product designed with no additional input



Figure 5.14. Tape Puller product in use

The tape puller product (Figure 5.13 and Figure 5.14) is a tape dispenser that is designed to be easily used with one hand. To use, a user would first insert a hand into the central hand hold. The end the tape is then attached to the edge of the box. The dispenser is then pulled across the top of the box to dispense the tape. There are a series of rollers around the outside of the dispenser to help make the dispensing of the tape more smooth. A cutting blade is attached behind the last roller. When the tape has been drawn across the box, the tape can be cut by a simple downward motion to bring the blade in contact with the tape. There were no differences between the designer specification and the fabricated version of this product.

5.4.2 None Team 2: Conveyor Product



Figure 5.15. Conveyor product designed with no additional input



Figure 5.16. Conveyor Product in use

The conveyor product (Figure 5.15 and Figure 5.16) is designed to automate the process of taping a box. A box is first loaded and placed on a small platform at the start of the conveyor belt. The conveyor belt is turned on and off by a switch on the side of the device. When switched on, the box is pulled under a tape dispenser. A tape dispenser is mounted on a horizontal platform. The platform can be moved up and down by using a blue colored handle that is integrated into the vertical support. An internal pulley system allows the taping platform to be moved up and down with little effort. The product also features a pair of guides that run along both sides of the conveyor belt. The guides can be adjusted by pushing or pulling on a second blue colored handle. Once the width of the guides and height of the dispenser have been adjusted, the user manually attaches the end of the tape to the leading edge of the box and turns on the conveyor. This pulls the box under the dispenser causing tape to be applied to the center. A spring mechanism on the dispenser causes a cutting blade to hit the tape and cut it once the box has passed through the device.

There were a few differences between the designer description and the fabricated version of this product. The biggest one was that the side guides were drawn by the designers as rollers. The fabricated version used simple wooden rails for the guides. The visual appearance of the dispenser area on the horizontal platform was a little different than drawn by the design team. A small cap was added to the dispenser to prevent the tape roll from sliding off the dispenser spool. This was needed because the implementation of the dispenser mechanism was a little different than in the designer prototype. Finally, a small amount of extra clearance was added between the vertical post and the handle used to slide the side guides in and out. The space was originally too small to accommodate a user's fingers.

5.5 Data Analysis

The evaluation data were analyzed to answer our three hypotheses:

H1: Designs resulting from input will embody greater Effectiveness, Satisfaction and Efficiency compared to designs using no input.

H2: Input from end users will result in designs that embody greater Effectiveness, Satisfaction and Efficiency compared to designs using other types of input.

H3: Input that is more directly associated with end users will result in designs that embody greater Effectiveness and Satisfaction than designs using input that is less directly associated with end users.

There were a number of failures during the evaluations where evaluators were unable to complete the task. An a priori decision was made to enter 300 seconds for failed tasks. This was the time that evaluators would have been stopped if they had not given up on the task but also had not completed it. All successful evaluations were completed in under 135 seconds, so the use of 300 seconds for failed tasks resulted in highly skewed data (Table 5.10). The descriptive statistics were also calculated with the failures removed.

Task failures are shown in Table 5.1 and Table 5.2. One evaluator, ES00002 was unable to even attempt the task with any of the devices. All data from this user was removed from further analysis since actually using the device is needed for an objective evaluation. The rest of the evaluators were able to use the devices and attempted the task. The data for these evaluators was kept since attempt the task with the device but simply being unable to complete it is valid data. However, since these evaluators were unable to

complete the task to provide valid efficiency data, failures were removed from all analysis of Efficiency.

Table 5.1 Task failures per device

Input	Device	Failures
user	Automated Tape Feeder Product	1
user	Tape Stamper Product	2
tool	Cabinet Mounted Product	2
tool	Table Mounted Product	2
OT	Wall Mounted Product	3
OT	Powered Pole Product	6
none	Conveyor Product	1
none	Tape Puller Product	2

Table 5.2. Task failures per evaluator

Evaluator	Products Failed
ES00001	1
ES00002	8
ES00007	1
ES00006	5
ES00003	2
ES00011	1
ES00012	1

The Total, Effectiveness and Satisfaction scores from the evaluation survey were calculated. Table 5.3 shows the averages of these scores along with the average ranking and the average to survey question 13 for each device.

Table 5.3. Averages for Total, Effectiveness and Satisfaction scores, average ranking and question 13

Device	Input Type	Avg Total Score	Avg Effectiveness Score	Avg Satisfaction Score	Avg. Ranking	Avg. Q13
conveyor product	none	41.05	14.47	26.58	4.79	3.26
tape puller product	none	38.95	11.58	27.37	4.74	3.16
cabinet mounted product	tool	41.74	13.37	28.37	4.42	3.58
table mounted product	tool	50.16	17.16	33.00	3.21	4.16
wall mounted product	OT	46.63	15.79	30.84	3.68	3.89
powered pole product	OT	38.95	11.58	27.37	4.74	3.16
automated tape feeder product	user	49.53	16.05	33.47	3.37	4.05
tape stamper product	user	39.21	12.32	26.89	5.21	3.16

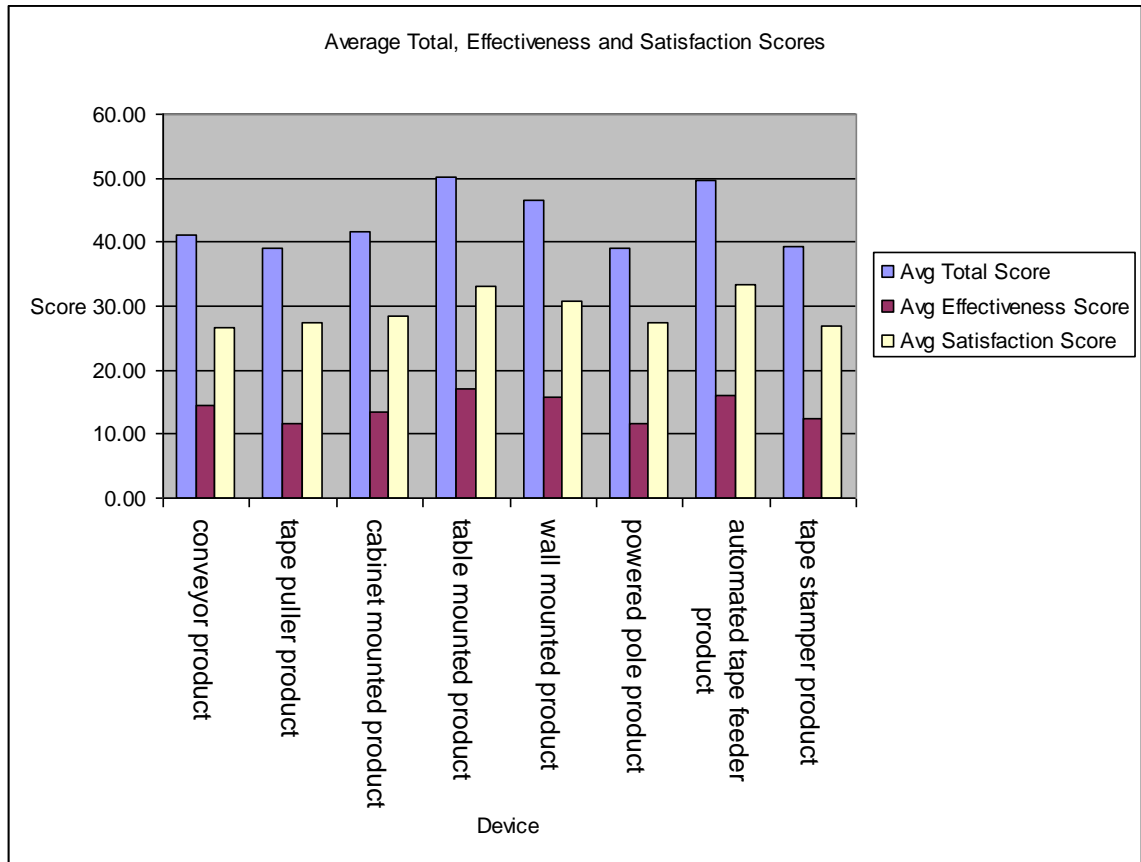


Figure 5.17. Graph of average total, effectiveness and satisfaction scores

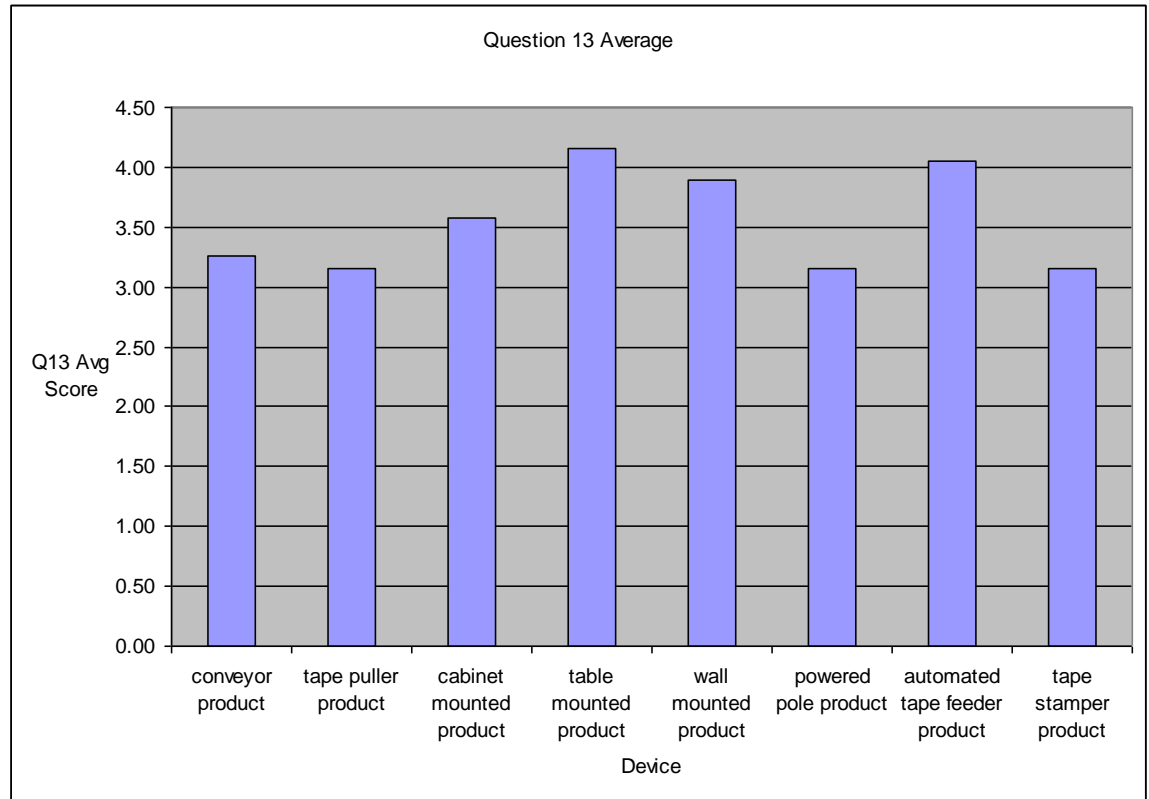


Figure 5.18. Graph of average score from survey question 13

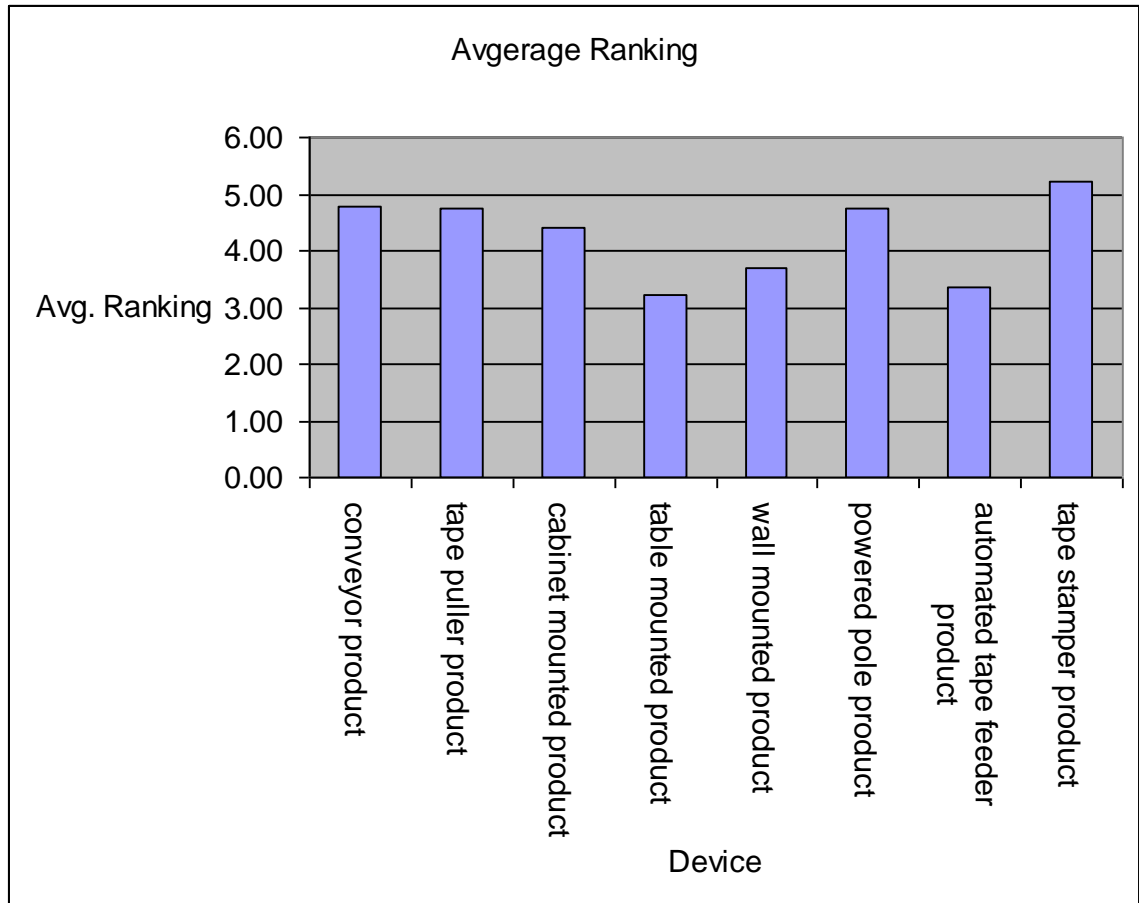


Figure 5.19. Graph of average ranking for each device

The correlation between the Total, Effectiveness, Satisfaction and Q13 values was calculated using the non-averaged values from each survey (Table 5.4). Spearman's rho was used since these values are ordinal, not ratio data. There is a very high correlation between these values (Table 5.4) indicating that the answers given on the evaluation survey, the evaluator's initial opinion of the device and the ranking survey were consistent.

Table 5.4. Correlation between Total, Effectiveness and Satisfaction scores and survey question 13

	Spearman's rho	p value
Total - Effectiveness	0.946	<.001
Total - Satisfaction	0.959	<.001
Total - Q13	0.872	<.001

The average ranking is shown in Figure 5.19. The ranking should move in the opposite direction from the other scores resulting in a negative correlation between the Total score and the overall rank. This is expected since higher scores and lower rankings are better. Spearman's rho between the un-averaged survey answers for Total Score and Ranking is shown in Table 5.5.

Table 5.5. Correlation between Total score and device Ranking

	Spearman's rho	p value
Total - Ranking	-0.627	<.001

Descriptive statistics are shown in Tables 5.6 - 5.8. The table is divided into sections that describe the data collected during the evaluation for devices designed with each type of input. The data from both devices designed with a given type of input are combined to look at the range of answers across both devices.

Table 5.6. Descriptive statistics for Total Score for each type of input

Descriptives: Total Score		
Input		Statistics
None	Mean	40
	Median	41.5
	Skewness	-0.009
	Range	36
	Minimum	24
	Maximum	60
Tool	Mean	45.947
	Median	48
	Skewness	-0.328
	Range	35
	Minimum	25
	Maximum	60
OT	Mean	39.289
	Median	40.5
	Skewness	-0.105
	Range	47
	Minimum	13
	Maximum	60
User	Mean	44.368
	Median	44.5
	Skewness	-0.472
	Range	43
	Minimum	17
	Maximum	60

Table 5.7 Descriptive statistics for Effectiveness Score for each type of input

Descriptives: Effectiveness Score		
Input		Statistics
None	Mean	13.02631579
	Median	14
	Skewness	-0.319321146
	Range	16
	Minimum	4
	Maximum	20
Tool	Mean	15.26315789
	Median	16
	Skewness	-0.437381206
	Range	13
	Minimum	7
	Maximum	20
OT	Mean	13
	Median	14
	Skewness	-0.234930603
	Range	16
	Minimum	4
	Maximum	20
User	Mean	14.18421053
	Median	15
	Skewness	-0.517246459
	Range	15
	Minimum	5
	Maximum	20

Table 5.8 Descriptive statistics for Satisfaction Score for each type of input

Descriptives: Satisfaction Score		
Input		Statistics
None	Mean	26.97368421
	Median	27
	Skewness	0.071143434
	Range	24
	Minimum	16
	Maximum	40
Tool	Mean	30.68421053
	Median	31
	Skewness	-0.306668726
	Range	24
	Minimum	16
	Maximum	40
OT	Mean	26.28947368
	Median	26.5
	Skewness	-0.063240789
	Range	31
	Minimum	9
	Maximum	40
User	Mean	30.18421053
	Median	30.5
	Skewness	-0.43223987
	Range	28
	Minimum	12
	Maximum	40

Table 5.9. Descriptive statistics for device Ranking for each type of input

Descriptives: Ranking		
Input		Statistics
None	Mean	4.763
	Median	5
	Skewness	-0.219
	Range	7
	Minimum	1
	Maximum	8
Tool	Mean	3.816
	Median	3.5
	Skewness	0.254
	Range	7
	Minimum	1
	Maximum	8
OT	Mean	5.132
	Median	5
	Skewness	-0.188
	Range	7
	Minimum	1
	Maximum	8
User	Mean	4.289
	Median	4.5
	Skewness	-0.060
	Range	7
	Minimum	1
	Maximum	8

Table 5.10. Descriptive statistics for Efficiency for each type of input

Descriptives: Efficiency			
Input		Statistics (seconds)	
		with failures	without failures
None	Mean	47.7	40.9
	Median	40.0	40.0
	Mode	40.0	40.0
	Standard Deviation	48.5	24.6
	Sample Variance	2356.5	605.7
	Skewness	4.0	0.7
	Range	292.0	97.0
	Minimum	8.0	8.0
	Maximum	300.0	105.0
	Confidence Level(95.0%)	16.0	8.2
Tool	Mean	38.5	24.0
	Median	15.0	14.5
	Mode	15.0	15.0
	Standard Deviation	68.0	27.7
	Sample Variance	4625.4	765.9
	Skewness	3.3	2.9
	Range	296.0	130.0
	Minimum	4.0	4.0
	Maximum	300.0	134.0
	Confidence Level(95.0%)	22.4	9.4
OT	Mean	77.6	27.3
	Median	29.0	17.0
	Mode	300.0	17.0
	Standard Deviation	108.6	20.1
	Sample Variance	11802.4	403.1
	Skewness	1.6	1.0
	Range	295.0	76.0
	Minimum	5.0	5.0
	Maximum	300.0	81.0
	Confidence Level(95.0%)	35.7	7.4
User	Mean	34.6	27.4
	Median	18.5	17.0
	Mode	4.0	4.0
	Standard Deviation	53.2	30.0
	Sample Variance	2830.1	899.4
	Skewness	3.7	1.6
	Range	298.0	116.0
	Minimum	2.0	2.0
	Maximum	300.0	118.0
	Confidence Level(95.0%)	17.5	10.0

The Total evaluation survey score and Ranking survey results were examined with the respect to the order that the devices were evaluated in to ensure that the evaluation order had no effects. Table 5.11 shows no correlation between the evaluation order and either the evaluation survey scores or ranking survey was found.

Table 5.11. Correlation between Total Score, Ranking and Evaluation Order

Correlations with Evaluation Order		
	Spearman's rho	p value
Total - Evaluation Order	0.092	0.261
Ranking - Evaluation Order	-0.038	0.646

5.5.1 Hypothesis Tests

Based on the very high correlation between the Total Score and the two sub scores (Effectiveness and Satisfaction) in Table 5.9 ($\rho > .94$), the decision was made to test the hypotheses using only Total Score. Using the Total Score (Total Usability) will simplify the analysis and should provide the same results. The Hypotheses can be restated in these terms:

H1: Designs resulting from input will embody greater Usability and Efficiency compared to designs using no input.

H2: Input from end users will result in designs that embody greater Usability and Efficiency compared to designs using other types of input.

H3: Input that is more directly associated with end users will result in designs that embody greater Usability than designs using input that is less directly associated with end users.

To test H1, H2 and H3, the Mann-Whitney test and Kruskal-Wallis test were applied. The Kruskal-Wallis test was applied first to determine if any significant differences across the different types of input. If a significant difference was found, the Mann-Whitney test was applied to determine which specific groups of data differed from one another. These non-parametric tests were also applied to Efficiency data since it was not all normally distributed.

A Kruskal-Wallis test was applied to look for significant differences in the Total Score, Efficiency and Ranking data between the four types of input. Significant differences ($p < .05$) were found only within the Efficiency data (Table 5.12). No significant differences were found between the inputs based on Total Score (Usability) or Ranking.

Table 5.12 Kruskal-Wallis test results comparing input types based on Total Score, Efficiency and Ranking

Kruskal-Wallis Test of Each Input Type Based on Evaluation Data		
	Chi - square	p
Total Score (Usability)	7.376	0.061
Efficiency	16.019	0.001
Ranking	7.051	0.07

Finding significant differences between the inputs related to Efficiency, Mann-Whitney tests were run between each pairing of inputs. The results are shown in Table 5.13. To accept H1, the Tool, OT and User devices would need to be significantly better than the None devices with respect to both Usability (Total Score) and Efficiency. They

are all better than the None devices in Efficiency but none of them were significantly better in Usability (Table 5.12). The data does not support H1 so it must be rejected.

To accept H2, the user input devices would need to be significantly better than devices produced with any of the other types of input with respect to Usability and Efficiency. No significant differences were found with respect to Usability and the User devices were only better than the None devices with respect to Efficiency. The data does not support H2 so it is also rejected.

Table 5.13. Mann-Whitney results of differences in Efficiency between inputs

Mann-Whitney comparison of Inputs based on Efficiency (seconds)				
	None	Tool	OT	User
None	X	Tool < None $p < .001$	OT < None $p = .018$	User < None $p = .002$
Tool		X	NS	NS
OT			X	NS
User				X

Based on these results, additional analysis was performed to study the equivalence between the two devices that were produced with each type of input. One of the assumptions behind combining both devices is each one device produced with a particular type of input would be similar to the other produced with the same input. A quick inspection of Table 5.1 shows that the scores between each pair of devices are very different in some cases. To determine if any differences between the pairs was significant, they were compared using the Wilcoxon signed rank sum based on the Total

Score. Results (Table 5.14) showed that only the None products were similar. All of the other pairs of devices showed significant differences ($p < .05$).

Table 5.14. Wilcoxon test comparing device pairs with relation to Total score

Wilcoxon comparison of devices based on Total Score		W	p
user	tape feeder-tape stamper	269	.003
OT	wall mounted - powered pole	246.5	.004
tool	table mounted - cabinet mounted	293	.023
none	conveyor - tape puller	349.5	.539

Since the differences were significant, each of the 8 products was individually compared with the others using Mann-Whitney based on Total score. The results are shown in Table 5.15.

Table 5.15. Mann-Whitney comparisons of all 8 devices related to Total Score

Mann-Whitney Comparisons of Each Device Based on Total Score (Usability)									
		Tape Puller Product	Conveyor Product	Table Mounted Product	Cabinet Mounted Product	Powerd Pole Product	Wall Mounted Product	Tape Stamper Product	Automated Tape Feeder Product
		None 1	None 2	Tool 1	Tool 2	OT 1	OT 2	User 1	User 2
Tape Puller Product	None 1	X	NS	Tool 1 > None 1 p=.003	NS	NS	OT 2 > None 1 p=.026	NS	User 2 > None 1 p=.004
Conveyor Product	None 2		X	Tool 1 > None 2 p=.006	NS	NS	NS	NS	User 2 > None 2 p=.011
Table Mounted Product	Tool 1			X	Tool 1 > Tool 2 p=.023	Tool 1 > OT 1 p< .001	NS	Tool 1 > User 1 p=.001	NS
Cabinet Mounted Product	Tool 2				X	Tool 2 > OT 1 p=.024	NS	NS	User 2 > Tool 2 p=.035
Powerd Pole Product	OT 1					X	OT 2 > OT 1 p=.004	NS	User 2 > OT 1 p< .001
Wall Mounted Product	OT 2						X	OT 2 > User 1 p=.042	NS
Tape Stamper Product	User 1							X	User 2 > User 1 p=.003
Automated Tape Feeder Product	User 2								X

These results show that even on an individual basis, user input did not always result in devices that were significantly better than devices produced with other types of input. In fact one of the tool devices (the table mounted product) beat one of the user devices (the tape stamper product). The analysis between the individual devices still provides no support for either H1. H2 cannot still be accepted as written. The ‘no input’ devices were never scored significantly higher than a device designed ‘with input’ (Table 5.15). At the same time, not all of the ‘with input’ devices were significantly better than the ‘no input’ devices.

User input during design was not always observed to result in a significantly better design than the other types of input (though it was never significantly worse). A Kruskal-Wallis was run to compare each device with the others with respect to Total Score (Table 5.16) to investigate how the directness of input affected the design:

H3: Input that is more directly associated with end users will result in designs that embody greater Usability than designs using input that is less directly associated with end users.

Table 5.16. Kruskal-Wallis comparison of study devices

Kruskal-Wallis Comparison of Study Devices Based on Total Score (Usability)			
Product Name	Input Type	N	Ave Rank
Table Mounted Product	Tool	19	104.26
Automated Tape Feeder Product	User	19	101.87
Wall Mounted Product	OT	19	91.21
Cabinet Mounted Product	Tool	19	72.42
Conveyor Product	None	19	68.29
Tape Stamper Product	User	19	62.47
Tape Puller Product	None	19	61.32
Powerd Pole Product	OT	19	44.5

The devices in Table 5.16 are shown in order of the average rank value from the test.

The type of input for each product corresponds to:

Tool -> User -> OT -> Tool -> None-> User -> None -> OT

The specific comparisons between each individual device can be examined in Table 5.15 to determine significant differences. For example, the top three devices (the Table Mounted Product[tool], Automated Tape Feeder Product[user] and Wall Mounted Product[OT]) are not significantly different from one another but the top two are both significantly better than the fourth (the Cabinet Mounted Product[tool]). To accept H3, the differences between devices designed with the different types of input the relationship between the products based on effectiveness and satisfaction would need to be, from best to worst: User -> OT -> Tool -> None. From the comparison of the devices, it is clear that the input less directly associated to the end users did not produce progressively lower levels of Usability. The expected significant relationships between the types of input is not observed, so H3 is rejected.

5.5.2 Comparisons with Level of Dexterity

The NHPT, DASH and Key Pinch tests were compared with the Total score to investigate how an evaluator's level of dexterity related to the evaluation of a device. These dexterity measures were chosen for the analysis by comparing correlations between them similar to how the total, effectiveness and satisfaction scores were compared. This analysis can be viewed in Appendix V.

CHAPTER 6

DISCUSSION AND CONCLUSIONS

This study was undertaken to determine how different types of input provided during the design process affected the usability and efficiency of the resulting design.

Generally, it was hypothesized that:

- Input of any type results in better designs than no input at all.
- Direct input from end users results in better designs than other types of input.
- The impact of input diminishes as it becomes less directly associated with end users.

These hypotheses are of particular importance in the design of devices for persons with disabilities because of the central role that input plays in helping designers to gain an end user's perspective of a design problem. To investigate them, varying types of input were given to design teams who were presented with a design task. The design process was controlled so that the only difference between the design teams was the input provided to them during the design process. The final designs were fabricated and then evaluated by end users to measure the level of usability (satisfaction + effectiveness) and efficiency of each.

6.1 Observed Effects

Designs were evaluated for effectiveness, satisfaction and efficiency. The survey scores for effectiveness and satisfaction were highly correlated with the total usability score (effectiveness + satisfaction), so the usability score was used in hypothesis testing. Efficiency was measured by task duration. The analysis had to accommodate task

failures in cases when evaluators were unable to complete the task. When the failures were removed, the efficiency data was still skewed leading to the decision to analyze task duration non-parametrically.

Hypothesis testing was done sequentially, from general to more specific using Kruskal-Wallis and Mann-Whitney analyses, respectively. This analysis combined the evaluation results of the two devices based upon the same input, resulting in four input groups. The analysis indicated that the groups differed in efficiency ($p=0.001$) but differences did not reach statistical significance in usability score ($p=0.061$) or device ranking ($p=0.07$). Subsequent Mann-Whitney analysis confirmed that the three input groups (user, OT, tool) had greater efficiency than the control group (No input). These results indicated that H1 and H2 cannot be accepted but that input did have a beneficial influence on task efficiency.

Combining usability measures assumed equivalence across devices designed with like input. Analysis showed this assumption to be false. Only the devices in the control group exhibited similar usability scores ($p=0.539$). The pairs of devices designed with user, OT or tool input had different usability score ($p<.0.05$). This finding led to the decision to analyze all 8 products separately (Table 5.15).

This individual device analysis showed that one device from each of the input types scored higher in total usability than at least one of the control devices. Specifically, the Automated Tape Feeder (user), and Table-Mounted (Tool) products scored higher than both of the control devices and the wall-mounted (OT) product scored higher than one of the control designs. This analysis also confirmed that User input did not always result in both higher usability and efficiency score compared to other input types.

The differences between the devices with respect to usability can be seen graphically in Figure 6.1. Each of the circles shows devices that were statistically similar to each other. Where the circles overlap also indicates statistical similarity. For example, the Automated Tape Feeder (User) and the Table Mounted (Tool) products were significantly

different than the Cabinet Mounted (Tool) and the Conveyor (None) products but are not significantly different than the Wall Mounted product.

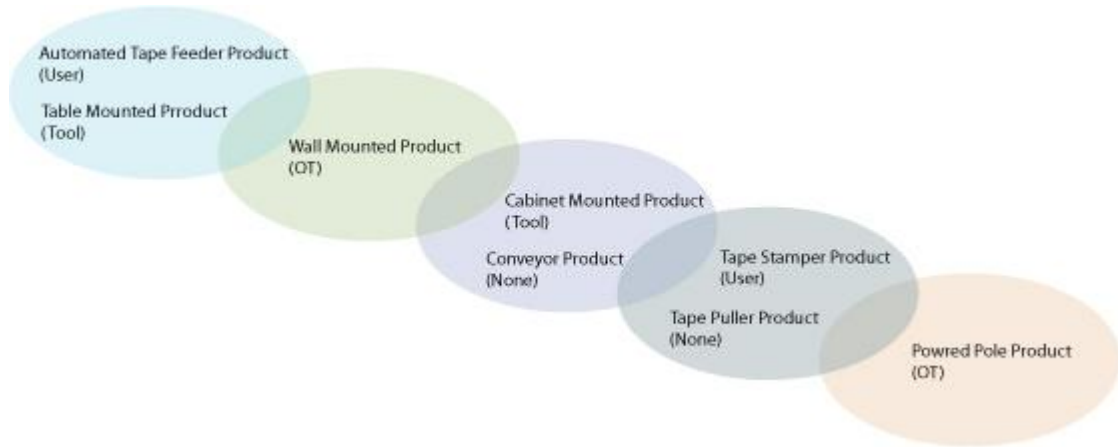


Figure 6.1. Graphical representation of the similarities and significant differences between devices based on usability.

While the hypotheses were rejected, results suggest that design input did help produce more efficient devices and also helped produce the three devices with the highest usability ratings. The results indicated that Tool input may be as useful as direct user input in some cases. They also showed that one product designed with OT input had the lowest usability score and resulted in the most task failures. In total, these findings can be used to review this project with respect to the design process and the many factors that influence design results.

6.2 Factors Affecting Design Input

The input utilized by designers during the design of a product is just one aspect of a complex process. Several factors were controlled during the design phase of the study. All teams were given the same information about the design problem and restricted from

performing outside research (such as from books, the internet, classmates or other sources). The input allowed to each design team was specifically provided to them in the form of simulation tools, a professional OT or a group of users.

The design methodology followed by the design teams was intended to be generically similar to practices used in industry. The timing and duration of each type of input was controlled. The simulation tools were available to design teams throughout design since they would generally be available to a designer at most any time. Time with the OT and with end users was scheduled since they are not typically a full time part of a design team and are not always available. Input sessions were scheduled at what are typically the most important times during the design process: at the beginning where the general concept and approach to the design solution are formulated and again near the end after the concept has been implemented but needs refinement.

The analysis of the device evaluations suggest that there are additional factors which play a role in how input is utilized during the design of an AT device. The factors include, but are not limited to: the ability of input to represent users with disabilities, the communication between stakeholders and designers, designer experience, and device fabrication. An understanding of these can provide valuable information about design process improvements which might be made.

6.2.1 Representative Input

To design a device that will meet the needs of a particular group of users, input must represent those users' needs so that they can be considered during the creation of the design solution. The effectiveness of each input used in this study was measured by how usable and efficient the final devices were to the evaluators. The evaluators were recruited so that they were representative of a wide range of dexterity limitations as measured by the DASH and other dexterity measures.

The various design inputs also represented a range of dexterity abilities, but each one was representative in a different way. The three simulation tools supplied to the design teams gave the designers the ability to personally experience different aspects of dexterity limitations such as reduced ability to grasp and hold objects and lower fine finger dexterity. Other teams did not benefit from this experience.

The Tool teams noted in their journals that the simulation devices have limitations and they recognized potential differences in the experience compared to possible real life situations. For example, a glove may simulate a reduction in fine finger manipulation but it also reduces the sense of touch. A real user's sense of touch may not be limited in the same manner, so the designer has to imagine what it might be like to have the reduced dexterity but normal sense of touch. One of the designers wrote about the fact that it was difficult to go "from 'smart' highly dexterous hands to 'dumb' low dexterity hands" in an instant by putting on the simulators. The simulation tools seem to have helped the designers become more aware of potential issues by providing a first hand experience of some issues, even though the simulation had some shortcomings.

The OT also represented a range of user function, based on the experience gained from working directly with many different end users. Unlike knowledge gained from direct experiences, the input from the OT provided secondary knowledge about the needs as well as information about strategies for meeting those needs of which an end user may not be aware.

The three end users were, of course, able to directly represent their needs and desires to the design team. Each of the users had different types of dexterity limitation and so was able to provide the design teams with varying perspectives based on their personal experience. The end users also tried to convey information to the design team about needs and problems that people with different types of dexterity limitations might encounter even if those needs were not experienced by them personally.

Designs based upon the three types of input received the highest overall usability ratings. This provides evidence that each was reasonably representative of the needs of the diverse evaluator group. However, there were nineteen cases where the evaluators were unable to perform the task of taping closed a box with the devices (Table 5.1). Seven evaluators failed to complete the task while using at least one device with two of the evaluators accounting for the majority of task failures (as mentioned, one evaluator could not use any of the devices). The inability of persons to complete the task is an indication that the specific limitations of those evaluators were not accommodated by the designs. In other words, the input upon which these designs were based did not adequately represent the capabilities of those evaluators. Of note is the finding that one device based upon OT input resulted in the highest number of task failures, while the other device based upon OT input was rated highly. This provides an indication that factors other than representativeness of input are involved. Design usability, therefore, reflected how well the input generalized to the broader population of persons with dexterity limitations but also reflected how well information was transferred to the designers and how well designers received that input.

6.2.2 Transfer of Information

6.2.2.1 Communication

If input representing the needs of the end users aids in developing a successful AT product, it is also important that the input is utilized effectively. It must be transferred from the source and received and understood accurately by the designer. Differing levels of communication were observed between the design teams and stakeholders. The stakeholders were instructed to let the designers lead with ideas, but otherwise the two groups were simply instructed to work together to find the best solution to the problem. The exact method of how the two groups interacted was left up to each team.

In some cases, the interaction seemed to work reasonably well and resulted in a more usable device (as in the Automated Tape Feeder Product [user] and the Wall Mounted Product [OT]). In other cases, this interaction did not translate into a more usable device (as in the Tape Stamper Product [user]) and may have even been counter-productive (such as the Powered Pole Product [OT]). The actual content of the input provided by the OT and by the users was very similar in many ways. As indicated by the journals kept by the designers, both of the stakeholder groups gave suggestions to generally make the devices simple, small and possible to use with one hand. If the input was similar, why did the resulting devices differ?

The use of multiple users but only a single OT to provide input seemed to affect the stakeholder/designer interaction. The multiple users seemed to make the dynamics of a larger group more collaborative. The mix of personalities provided a better chance for more outgoing personalities to be present to lead the discussion. With only a single OT, the smaller group was more intimate. Individual differences in personality appeared to have a bigger effect on how well a smaller group communicated. In each of the scheduled input sessions, the users and designers were constantly engaged in a very collaborative atmosphere. The designers would suggest ideas and it would be discussed and refined. In contrast, the designers and OT were much less interactive. During the input sessions, the designers tended to ask a few questions, listen to the answers from the OT and then work amongst themselves for a period of time before coming up with a few more questions. There was much less back and forth discussion between the OT and the design teams. The sessions were more like a presentation than a discussion or collaboration.

The users were also more outspoken about their ideas and preferences. They were more forceful in explaining why ideas may or may not work and in suggesting possible alternatives. They were also quick to reject ideas that might be feasible but that they did not like (while still explaining why they may not have liked it). By comparison, the OT

was less likely than a user to completely reject a design idea. If an idea presented by the designers could possibly work, the OT was more likely to suggest how it could be improved regardless of personal preferences. The OT teams seemed to focus their time somewhat more on refining an idea to make it as good as possible compared with the user teams which seemed to spend more time searching for ideas that they liked before working on refinements.

While both stakeholder groups emphasized simplicity in the design, what each group considered acceptable was different. A case of this is the powered pole product (Figures 5.5 and 5.6). The design team came up with the concept with the idea of eliminating almost all need for an end user use their hands to tape closed a box. The original concept was made up of four vertical poles and an elaborate mechanism for closing the box and applying tape. The feedback from the OT helped the design team simplify the concept and interaction with the device to make it easier to use. Even so, the final product was still rather complex, and, in fact, accounted for the most task failures and a poorly rated product. So, while the design team sought to accommodate people with very poor upper extremity function, they ended up with a design that was usable by the fewest types of people. While the OT expressed concern about the complexity, the idea itself was feasible so refinement rather than a simpler design concept was encouraged. This proved to be an ineffective transfer of information.

This project did not specify methods for interaction, so the quality of the information transfer was more dependent on how well the individual designer/stakeholder groups worked together. The eventual quality of the transfer depends on the content of the information as well as designers' ability to understand its implications and apply it to the design in an effective way.

6.2.2.2 Designer Experience

A designer's level of experience can contribute to how well input is understood and assimilated into a design. The goal in creating the design teams for this study was to

make everything equal between them as much as possible. The use of students ensured that all of the designers had similar levels of design experience. This includes experience both in things that they had designed (such as class projects) and design knowledge that they had learned (from the standard curriculum). Designers with experience related to designing any type of assistive technology or close personal experience with people with disabilities were specifically excluded. In one way excluding designers who were specifically interested in AT almost seems backward. They would appear to be ideal candidates for such a study. However, this helped to ensure that no team had knowledge about AT that other teams did not also have. Additional knowledge would have made the effect that the provided input had on their design more difficult to measure. Randomly assigning design team members was meant to further assure that any unevenness in either design skill or knowledge was spread out evenly.

The designs produced by the no input teams were not evaluated significantly different from one another. This does not mean that all groups were equal in design skill, but this result adds validity to the process used to form equivalent design teams. However, there were significant differences between the designs produced by all of the teams that did receive input. This finding might be explained by the designers' experience or differences in their ability to receive and utilize input.

The designers all had experience obtaining input through simulation tools and live users through their studies. One possible reason that the designs produced with live stakeholder input were so significantly different is that the designers simply did not have a great deal of experience in working directly with stakeholders. Each of the designers had worked on one project as part of their coursework that required them to work with a stakeholder during their design. So while they had experience with this it does not mean that all of the teams were equally skilled in effectively utilizing their interaction with the stakeholder. For more experienced designers, such as those who have worked a great deal with stakeholders, the detailed information that can come from professionals or end

users may have much more benefit. Experience can bring greater ability to sift the information to obtain what they need. Experience also allows designers to apply a greater body of past knowledge and strategies to the information they gather to find solutions.

The differences between the devices produced with Tool input were also significantly different from one another; however the designers may have been more experienced with using simulation tools and integrating their findings into their designs. One of the common questions asked by the designers (on the non-Tool teams) was whether or not they could use some form of tool. This was explicitly forbidden in the additional instructions provided to each team, but several designers commented that if it had not been prohibited, they would have done things like use gloves or tie their fingers together. This does show that simulation is a strategy that is commonly employed by designers to gain perspective on a design problem.

6.2.2.3 Availability of Input

The total amount of time that each of the design teams had access to their source of input is another potential factor in the differences between the devices. The tool team had access to the simulation tools for the duration of design while the stakeholder teams were only able to work with the stakeholders during the scheduled sessions. There was an assumption before beginning the design phase that as long as the design teams were allowed enough time to gather input they needed, additional input would not help very much. This is based on the idea that a particular type of input can only provide a certain amount of benefit. More time would not necessarily confer additional benefit; that would require better input. As mentioned earlier, design teams may still have been different in their level of skill and experience which will affect how well they are able to utilize input. Differences could mean that one team might have needed more time with the stakeholders to derive the same level of benefit from the input as the other team.

6.2.3.4 Fabrication

Each of the designs was fabricated by a single person in an attempt to ensure that the build quality of each was of a high level, consistent and appropriate to actually be used by a real user. The quality of the prototypes produced by the design teams varied greatly and using them would certainly have introduced noise into the evaluations. Even so, the fabrication process itself also influenced device evaluation. Though the goal of the design teams was to produce a fully working prototype, that goal was not accomplished by each team. The fabricator had to complete design details and devise mechanical solutions for some of the devices. The defined task for the device to perform, sealing a box, is fairly complex and designs incorporated different mechanical and electro-mechanical components. The design teams were hindered to some degree by not being able to do external research which prevented them from identifying mechanisms and finding technical solutions on their own. The requirement to build a working prototype was imposed to help ensure that all mechanisms were practical and effective.

The fabricator was provided with the prototypes, shop drawings and product description, which included detailed descriptions of exactly how each part of the device was supposed to work and how the user was to interact with it. Since the mechanics were not always specified, the fabricator was challenged with devising a way to implement the functionality without altering the form of the design or how the user interacted with it. This was a particular challenge with the User input devices. For example, although some of the materials used in fabrication were different, the final mechanisms in the Automated Tape Feeder Product worked as described by the designers. However, the mechanism for the Tape Stamper Product was not the same. No solution was found to actually ‘stamp’ tape straight down. The final mechanism required users to slide the device across the box to apply tape (otherwise it would jam) or come up with some alternate method for using it (which many users did). Changes to design specification such as using alternate materials to lower costs or to make the device better fit the manufacturing process can be

introduced during fabrication (Ulrich and Eppinger 2003). All of the components of a design are typically fully specified at this stage. This example highlights the importance of building and testing components before fabrication so that, even if changes are necessary, the final version has a better likelihood of functioning as intended.

6.3 Measures and Instruments

The evaluation survey was tested and showed high levels of consistency. The very high correlation between the Effectiveness and Satisfaction scores brings up the question of whether the items on the survey intended to measure these constructs were actually measuring them. While these two constructs are definitely related, they are not necessarily the same. The survey does appear to be reliable for measuring total usability. Items targeting effectiveness and satisfaction included constructs identified in the literature. For Effectiveness, the survey included items related specifically to how well the device actually performed the task or whether it solved problems encountered by the user (Mao, Vredenburg et al. 2005; ISO/IEC 2006). For measuring Satisfaction, items focused on ease of use, comfort, understandability and safety (Connie and Hershler 1991). Also included in satisfaction were aesthetics of the device (Hocking 1999; Newell 2003) as well as the social acceptability (Hocking 1999). The specific questions intended to measure Effectiveness and Satisfaction should be refined in future surveys to ensure that they are more sensitive to these individual constructs.

6.4 Improvements to the Study

There are a number of improvements that might be made to this study. The first would be in the composition of the design teams. Utilizing students provided a good way to select from a pool of designers with very similar experience. The results indicated inconsistent abilities in utilizing the different types of input. More experienced designers may have been more consistent in this regard. Despite this, using students does appear to

be a good strategy for building balanced design teams. One way to mitigate the lack of experience in utilizing the inputs might be having the design teams follow the same methods for interacting with users. Perhaps a structured discussion or some other method could be used to bring more consistency to the designer/user interaction. Designers could receive training in the technique pre-study to ensure that each designer can utilize it effectively.

Another modification might be to include an engineering designer on each team along with the industrial designers. The restriction on outside research was necessary but proved to be a big hindrance to the teams. Mechanical issues are something that they would normally research. The inclusion of an engineering designer as part of the team may have allowed the teams to explore additional design possibilities that they were unable to because of the external research restriction. Students might make good subjects for the engineering designers for the same reasons (similar experience/knowledge) as student industrial designers. It is worth noting that this would certainly change the dynamics of the team and essentially create a multifunctional design team. This is not necessarily bad, since multifunctional design teams are common (Clark and Fujimoto 1989; McGrath, Anthony et al. 1992; Swink, Sandvig et al. 1996), but it could introduce possible tension between team members from different disciplines about the best design solution. This might aid or hinder the design, but either way it does potentially add an additional variable.

Alternatively, including the device fabricator (or a representative of the fabricator) on the design team may have provided a controlled means to address mechanical and fabrication issues. The fabricator would need to be given instructions similar to those given to the stakeholders in this study to prevent contaminating the design teams with ideas that didn't originate from the designers and/or input. This would eliminate the need to add additional opinions to the team since the fabricator would simply be a resource for what is possible rather than a source for possible design solutions.

6.5 Areas for Further Study

There are a number of areas, especially related to the transfer of design information that might benefit from further study. The first is related to the communication and whether different types of input have different levels of impact on the design of devices for different types of disabilities. In other words, do the various types of input provide the same levels of benefit when the design problem is focused on a different limitation, such as dementia, as they do for dexterity limitations? In this example, since users with dementia are typically unable to express their needs directly, would input from professional therapists be more effective? Is simulation still as effective as observed in this study? Products designed for people with different limitations can be improved by understanding which types of input are most effective. This may lead to an understanding of which conditions might make certain types of input better than others at communicating need information to designers.

Another area for further study would be to investigate how a designer's experience affects their ability to utilize input in AT design. Specifically does previous experience in designing AT products allow a designer to better utilize input to create a better assistive product? Design experience plays a large role in how a designer collects and synthesizes information to create a design. It would be very interesting to determine what effect previous experience specifically designing AT products has on the utilization of input. Such a study would be different from this one as it would be focused on understanding the actual design steps (i.e. what types of information do designers collect and how and why do they use it in the design). If positive differences do exist, a goal would be to identify what those differences are. If AT designers have learned techniques that enhance their ability to design assistive devices, it would be very useful in improving the training of new designers.

Finally, it would be useful to study the effect that different inputs have on a design based on its level of availability. It was generally assumed in this study that a particular type of input would only confer a fixed level of benefit to a design, even if it was available to the design team for a longer period of time. An approach for such a study would involve varying the length of input to different design teams. This might involve making stakeholders fully available to a design team at any point during the design process but only at scheduled times (as in this study) to another team. Making stakeholders always available is not necessarily standard practice, but it would be useful to understand whether more of the same type of input provides better results. It would still be important to attempt to create equivalent design teams, though this study showed that can be a difficult task. To counter this uncertainty, it might be useful to focus on a single type of input. Several teams can then be given input for a particular duration while several others for a different duration to see if an overall trend emerges. The study could also show if designers require and/or utilize input heavily outside of the ‘typical’ concept or detail phases of design.

6.6 Conclusions

Designing a product is a complex process. In a real world design project, factors such as resource management (people and costs), marketing, and company strategy are added to more design-centric concerns like problem solving and creativity. All of these things can put constraints on a design and potentially have a large impact. The design of a product can be helped or hindered by management, the design process itself (such as the methods, philosophy, etc) or information. In other words, the output of the design process might be improved by better management of organizations and resources, by improvements to the methods that define how the actual design is carried out, or by improving the quality of information that is put into the entire process.

This study was focused on investigating how information that is put into the design process affects the resulting product. It is generally assumed that input during design is useful, but it can be hard to make decisions about how much or what kind of input is needed if all you can say about it is that “it is important.” One of the goals was to gather some controlled experimental evidence to show that input during the design process is more than just a helpful option to a design team. The results show that input can be a significant factor in improving the usability and efficiency of the final design. Since many design philosophies emphasize the gathering of various types of input to use during the design process this is a good confirmation. If it was not shown that input actually contributed to product improvements then the need to put a lot of it into the process could be questioned. If it had no measurable impact then spending time and money collecting it would be wasted effort.

Another aim was to measure relative effectiveness of different types of input since knowing if certain are better than others would be useful. If the effects are measurably different, an AT company might be able to look at the costs involved with utilizing various types of input and weigh them against a good estimation of the benefits to the completed product. Decisions of when to utilize various inputs could then be made within existing processes or by using methods such as DSM (Appendix L) to streamline the design process. It was observed that input during design can indeed be beneficial but one type was not definitively better than another. Still, the results point to some areas of input that can benefit AT design process.

6.6.1 Simulation Tools in AT Design

It was shown that, all other things being about equal, simulation can be just as effective as input from end users. The designers were provided with three relatively simple tools for simulating dexterity limitations. Using these, one of the teams was able to create a design (the Table Mounted Product) that addressed the needs of a wide range

of end users. It was evaluated just as highly as the Automated Tape Feeder product which benefited from direct user input during design. The Tool input device actually had higher overall total scores than the User input device in this case though statistically they were equivalent.

A stronger focus on simulation in AT design, using tools that can accurately simulate a condition, may be very effective and beneficial to design process improvement. They would eliminate the time needed to search for and recruit a representative group of users along with everything involved with scheduling time between users and design teams, preparing for those meetings and capturing all of the information collected for future use. Simulation tools can allow designers to investigate issues as they arise during design without having to worry about trying to learn about everything they might need to know during a few scheduled sessions. This particular situation was observed a few times during the study where design teams working with stakeholders commented in their journals that they wished that they could have more time with the stakeholders or that they were available when new questions arose during the design process.

Of course, increased use of simulation in AT design would require using tools that accurately reflect user issues. There could be a great benefit in engaging end users creating accurate simulation tools if they don't already exist or in improving ones that already do. These tools would allow designers to experience limitations representative of the users who participated in developing the tool so that design problems can be investigated and solved as they arise. This can help to eliminate repetition of design tasks (iteration) and reduce overall development time. For an AT company, this can reduce the amount of end user engagement, with the time and expense that it involves, that might normally be needed to produce a good product.

This is not to say that simulation tools should replace direct user input. While it appears that they can be very effective, so is user input. It is not clear whether the benefits provided by the simulation tools are the **same** benefits provided by end users.

The way that designers interact with simulation tools compared to end users is obviously different. A design team could create a highly rated device from learning about certain aspects of the design problem from a tool and a different team could also create a highly rated device by learning about slightly different aspects of the design problem from stakeholders. Though the end results are similar, it is very possible that what is learned from one source compared to the other are not the same. If this is the case, using input from both tools and stakeholders during design may result in additional benefits by revealing aspects of a problem to a designer that they might not be able to learn about from a single source of input.

6.6.2 Improving Communication

This study also found that input can contribute to the design of devices that are more effective and usable than if no input is used, but the effects of input can be highly variable. The inconsistent benefits of input can be influenced by how well the input represents the end user group, the designers' level of experience and, most importantly, by how well information is transferred from the input to the designer. The ability to transfer this information gets back to the issue of stickiness (von Hippel 1994). One of the objects of input is to 'un-stick' information so that designers can access it and use it more easily. It would have been a useful finding if one type of input was clearly better than the others.

Instead, evidence showed that all of the inputs studied can be effective, but they depend on how well the designer can understand them. In the case of tools a designer must of course be able to use the tool properly to explore design solutions through the first hand experience gained by using it. The keys for this interaction are that the tool must be reasonably accurate so that the designer can draw correct conclusions from its use and more experience with using tools may allow the designer to utilize tools more effectively. Many of the designers said that they would naturally try to simulate known

conditions on their own if it had not been prohibited. This is potentially important because it suggests that designers will attempt to do this naturally. If so, over time designers are likely to become more adept at utilizing simulation making it a powerful way to un-stick information about an AT design problem.

Input from stakeholders presents other challenges. The quality of the input depends largely on two factors: 1) how well stakeholders can generalize their personal experiences to the broader population of users, and 2) how well the designers and stakeholders are able to articulate their ideas to one another. Stakeholders - whether end users or professionals - are not necessarily equally adept at representing a wide range of functional abilities while providing input. In addition, designers must be able to ask questions so that they are understood by the stakeholders and the stakeholders must be able to reply in a way that can be correctly understood by the designers. This makes sense, but since designers and stakeholders do not necessarily speak the same 'language' it is an important issue. Since stakeholders are generally not designers themselves, it may not make sense to expect them to speak in 'design' terms. At the same time, most designers are not disabled and so it is unlikely that they will naturally be able to speak in the same terms as stakeholders. This highlights the need for methods that can be used to facilitate accurate communication between the two groups so that when stakeholders are engaged during design, needs and ideas can be accurately and efficiently exchanged.

APPENDIX A

PRE-FOCUS GROUP

A.1 Pre-Focus Group Email Invitation

Greetings,

We would like to invite you to participate in a focus group to with the goal of identifying design related problems with several common office related products. The issues identified by this focus group will be used in a future study to re-design one of the products that will be discussed. Identifying real problems that are encountered by users of these products is an important first step making future products more usable and improving satisfaction.

The focus group will be held at the Center for Assistive Technology and Environmental Access (CATEA) on the campus of the Georgia Institute of Technology on October 23, 2008 starting at 6:00pm. The focus group session will last for about 2 hours. Light refreshments will be served. Each focus group participant will receive \$50 in compensation for their time at the completion of the focus group session. If you are interested in participating in this focus group, please indicate your interest by sending email to Young Mi Choi at:

removed@mail.gatech.edu

Please include your name, email address and a contact phone number in your email.

An audio and video recording of the focus group session will be made. All information collected by this study will be kept confidential and will only be accessible by study staff for this project and only from within the College of Architecture on the Georgia Tech campus. Your name and any other fact that might point to you will not appear in any publication. Audio and video recordings will be kept for no longer than one year. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB (Institutional Review Board) may review CCN records. The Office of Human Research Protections may also look at the records. Again, your privacy will be protected to the extent allowed by law.

Your participation is strictly voluntary and you are not required to participate at all. If you choose to participate, you may withdraw for any reason at any time. Keep a copy of this letter for your records. You do not waive any of your legal rights by participation in this study.

There is minimal potential risk and discomfort from participation in the focus group. The

risks involved are no greater than those involved in daily activities such as attending a meeting or public gathering. The only direct benefit to you for participation is the compensation of \$50 at the end of the focus group session. You are not likely to benefit directly in any other way from participation in the focus group. Indirect benefits include the opportunity to participate in research and the opportunity to improve the products and services used by you, your family and friends.

If you have any questions about the CATEA Consumer Network (CCN) you may contact Robert Todd at xxx-xxx-xxxx. If you have any questions about your rights as a research volunteer, call Ms. Melanie Clark, Georgia Institute of Technology at xxx-xxx-xxxx.

If you are interested in participating in this focus group, again, please indicate your interest by sending email Young Mi Choi at the following address:

removed@mail.gatech.edu

Please remember to include your name, email address and a contact phone number in your email.

Thanks for your support,
Young Mi Choi

Ph.D. Student, College of Architecture
Georgia Institute of Technology
Center for Assistive Technology and Environmental Access
(CATEA)

A.2 Pre-Focus Group Moderator Script

The goal of our group discussion today is to identify some of the work tasks that you have difficulty doing because of your limited dexterity. One of the problematic tasks that we identify today will be used in an upcoming study where groups of designers will be challenged to develop an assistive product that will aid in performing that particular task.

We will follow a particular format for our discussion today. First we will discuss a list of several common tasks that we have pre-selected. For each task we will spend some time focusing our discussion on how different aspects of dexterity affect your ability to

perform that task. After discussing the pre-selected tasks, we will spend some time identifying and discussing other tasks with which you commonly have difficulty.

Before we begin, let me suggest some things that will make our discussion more productive. Please speak up and only one person should talk at a time so that everyone will be able to hear you. As a reminder, we are also tape recording the session, so these two things will help ensure that we don't miss any of your comments. We'll be on a first-name basis and we've placed name cards on the table in front of you to help us remember each other's names.

We also have a question before we begin. We would like to make a video recording of our discussions today. This was not asked in the original invitation that some of you received, so we want to make sure that this is OK with everybody here today. We want to be sure we can capture any visual demonstrations that you make during our discussions that are not easily captured by audio alone. As with the audio, it will only be viewable by study staff and will not be kept for more than one year. However if anyone feels uncomfortable about being video taped for any reason then no video will be recorded. My role here is to facilitate the discussion. I will ask questions and listen. I won't be participating in the conversation, but I want you to feel free to talk with one another. I'll be asking about a dozen questions, and I'll be moving the discussion from one question to the next.

There is a tendency in these discussions for some people to talk a lot and some people not to say much. But it is important for us to hear from each of you tonight because you have different experiences. So if one of you is sharing a lot, I may ask you to let others talk. And if you aren't saying much, I may ask for your opinion. Let's begin. Let's find out some more about each other by going around the table....

Starting the Focus Group (Ice-breaker question):

Please introduce yourself. Tell us a little bit about what made you interested in coming today and a little bit about what kind of work that you do.

Main Content, Focus group questions and probes:

For the first part of our discussion we will focus on three types of tasks: connecting peripheral devices to a computer, packing boxes to be mailed, and finally filing documents. We have items here today that are used in each of these tasks. Before we discuss the tasks, we want to give you a chance to perform each so that any problems you encounter are fresh in your minds for our discussion. However, keep in mind that these are just a small sample of items that are used. You may have used others in the past and encountered other difficulties. So, please keep any other experiences in mind because we are interested in hearing not just about difficulties you may experience with the items here today, but with any difficulties you have encountered in the past.

We have listed the activities to try for each task. Let's divide into three groups and spend a few minutes to try each.

[Here, divide the participants into three groups and give about 5 minutes for each group to try out each task]

[Connecting Peripheral devices to a computer]

Let's start by talking about connecting peripheral devices to a computer. This could be things like keyboards, mice, printers and scanners, but also other things such as cameras, cell phones, portable hard drives, or USB thumb drives.

- Did you have difficulty performing this task? What types of problems did you encounter?

(possible probe questions)

- What types of problems do you currently experience with reaching or accessing the connection ports on a computer?
- Are the connection ports in difficult to reach places?
- Are the ports at odd angles that make plugging devices in more difficult?
- What types of problems do you experience with holding the cables or connectors that connect a device and the computer?
- Are there particular aspects of the cables or connectors that make them difficult to hold or grip?
- Are there any particular aspects computer peripherals themselves that you have experienced that make them difficult to hold, grasp or manipulate?
- Does the task of connecting devices to a computer require fine finger manipulation that makes the task difficult or impossible for you to perform?
- Out of the problems that we have discussed, what would you consider to be the biggest one?
- Can you think of things that would help make it easier for you to connect peripheral devices to a computer? Are there any special things that you already do that make this task easier?

[Packing boxes to be mailed]

Next, let's discuss the task of packing a box with an item to be sent through the mail.

- Did you have difficulty performing this task? What types of problems did you encounter?

(possible probe questions)

- Do you experience any problems with the standard boxes, such as the collapsible type boxes that you can find at places like the post office or UPS store?
- What problems do you experience with closing and securing the package?
- How do you close and secure a box that you will mail? Do you use packing tape, do you wrap it or do you use some other method?
- Do you run into any problems closing and securing the package specifically related to grasping, holding or squeezing?
- Do you encounter any problems related to attaching address labels?
- Describe how you would attach an address label to a package?
- In what ways does a limitation in grasping, holding or fine finger manipulation impact your ability to address a package?
- Out of the problems that we have discussed with packing a box for mailing, what would you consider to be the biggest one?
- Can you think of things that would help make it easier for you to package a box for mailing? Are there any special things that you already do that make this task easier?

[Filing documents]

Let's move on now to the task of filing documents.

- Did you have difficulty performing this task? What types of problems did you encounter?

(possible probe questions)

- What types of problems do you encounter with file folders?
 - Do you encounter problems grasping or holding file folders?
 - What kinds of problems do you have with putting documents into file folders?

- What kinds of problems do you have with taking documents out of file folders?
- What kinds of problems do you have with labeling file folder tabs or attaching tabs to file folders?
- What types of problems do you encounter with finding and accessing stored files?
 - Have you experienced problems with accessing files within cabinets? If so, please describe them.
 - Have you experienced problems with accessing files that are stored on shelves? If so, please describe them.
- Have you experienced any other problems with grasping, holding, or manipulating files that have not yet been mentioned?
- Out of the problems that we have discussed, what would you consider to be the biggest one?
- Can you think of things that would help the task of filing easier? Are there any special things that you already do that make this task easier?

[User issues]

For the next part of our discussion, we want to identify other tasks that you have encountered difficulties with performing common tasks that are due to limitations in grasping, holding, squeezing, reaching or fine finger manipulation. This can be anything that you encounter in the course of doing things at home or at work. Remember that not all work is done in an office setting. We are interested in finding out about any task related to performing work; this could be in an office setting but it could also be in places like in a factory, in your home, or anywhere else. We will write the issues on the board to keep track of everybody's ideas.

(Possible prompt)

- Think back on a typical workday. What tasks do you do a lot that you find particularly hard or frustrating to perform?

[This next phase of the focus group discussion will depend partly on time. If the first part has generated a lot of discussion, then this is very good. However, we want to make sure to at least get a list of user supplied issues from the focus group session and have the users identify the most important ones.

If the first part has not generated much discussion, then we will want to spend time discussing the top issues mentioned by the users and collect as much detail as we can about the issues they have with those tasks that are related to dexterity.]

What we want to do next is identify the top two or three issues that we have listed and then discuss them further. Each, of course, is important, but to help our discussion we want to identify as a group the ones that affect the most members here.

[Once the top two or three have been identified, each should be discussed, depending on the time available, using the following questions.]

Now that we have identified a few specific tasks, let's discuss each one individually.

- What are the aspects of this task that you find difficult to perform? Please describe how limited dexterity makes it difficult.
 - What problems do you encounter with the task that are related to grasping?
 - What problems do you encounter with the task that are related to holding?
 - What problems do you encounter with the task that are related to squeezing?

- What problems do you encounter with the task that are related to fine finger manipulation?
- Out of the problems we have discussed, which would you say is the biggest one?
- Can you think of things that would help the task easier to perform? Are there any special things that you already do that make this task easier?

Concluding Remarks:

Thank you very much for participating in this focus group and sharing with us your experience with work related tasks. Before we wrap up this discussion, I would like to ask you, if we have missed anything that you feel is important?

Once again, please allow me to convey our sincere gratitude for your time and thoughts. If you have any questions or concerns after we finish, please contact Young Mi Choi at removed@gatech.edu or by phone at xxx-xxx-xxxx.

A.3 Pre-Discussion Tasks

Task: Connecting Computer Peripherals

- 1) Try inserting and removing a photo memory card in the card reader.
- 2) Try connecting and disconnecting a portable hard drive to the USB ports.
- 3) Try connecting and disconnecting a USB thumb drive.

Task: Packing Boxes for Mailing

- 1) Try putting various items in the boxes as if you were going to mail them.
- 2) Try taping the filled box closed.

- 3) Try adding an address label to the box.

Task: Filing Documents

- 1) Try adding and removing documents from the different types of file folders.
- 2) Try labeling the different types of file folders.
- 3) Try placing the file folders into and taking file folders out of different drawers (low and high ones) in a filing cabinet.

A.4 Pre-Focus Group Detailed Results

A.4.1 Purpose

The purpose of this focus group is to inform a future design study that will investigate the effect of user input on an AT product when the input is supplied during the design process. The objective was to identify the needs and issues that people with dexterity limitations encounter while performing work related tasks. The content of the group discussion was then analyzed to identify a task that would be suitable for use in the design study.

A.4.2 Procedures

The focus group was conducted on October 23, 2008 from 6pm-8pm in the Usability Lab at the Center for Assistive Technology and Environmental Access (CATEA). It was funded through the Rehabilitation Engineering Research Center for Workplace Accommodations. Video and audio recordings were made of the focus group session. Each volunteer focus group member received \$50 compensation for their time at the end of the focus group session. A single moderator led the group discussion using a prepared

script. There were also two additional staff, one who wrote participant comments on a Post-It Easel Pad and another taking notes of participant comments.

A.4.3 Recruitment

Participants were recruited to take part in a focus group to discuss problems that they have encountered in performing work related tasks. Focus group participants were recruited primarily through the CATEA Consumer Network (CCN). The ideal number of members targeted for this focus group was 6-8 total participants. An e-mail invitation was sent out to the CCN to recruit members with limitations in dexterity (grasping, holding, reaching, squeezing, fine finger manipulation) for the focus group discussion.

8 CCN members in the Atlanta area were invited to participate who matched the inclusion criteria for the focus group:

- had a dexterity limitation
- working aged adults
- were in the Atlanta area (to come to the focus group meeting)
- did not have a sensory limitation (vision or hearing)

Members with sensory limitations were excluded to try to help ensure that the group remained focused on the physical issue of limited dexterity.

Three of the CCN members who were asked to participate in the focus group were unable to attend. This would have been below the targeted number of participants so some additional members were sought. An email was sent to contacts at several local

organizations asking them to forward the focus group invitation to one or two people who might be interested in participating (who met the criteria above). This was sent to contacts at the Shepherd Center, ADAPTS (Access Disabled Assistance Program for Tech Students), disABILITY Link and Emory Healthcare. Three additional participants expressed interest through these contacts. The invitation material was also sent to a generic contact email address at the Bobby Dodd Institute, United Cerebral Palsy of Georgia and the Tommy Nobis Center; however no response from anyone in these organizations was received.

The total number of participants in the focus group was seven. There were five men and two women. The participants represented a wide range of occupations. The occupations included a student, a retired locksmith, a pharmacy worker and a motivational speaker. Most of the participants experience dexterity limitations due to spinal cord injuries. For other members, their dexterity limitations were due to conditions such as Parkinson's or stroke.

A.4.4 Methods

The script followed during the focus group was aimed at discovering the specific issues that participants experienced in performing work tasks because of limitations in their ability to grasp, hold, reach, squeeze or perform fine finger manipulation. The focus group session was divided into two parts. The first part focused on discussing three specific work related tasks that had been selected for discussion before the focus group. The tasks were:

- Plugging peripheral USB devices into a computer
- Packing a box to be mailed
- Filing documents

Items related to each of these tasks were available at the focus group session. Before discussion began, the users were given time to perform a list tasks with the items so that issues would be fresh in everyone's mind.

The second part of the focus group was focused on collecting a list of other tasks that the group members often experience difficulty in performing. For this part of the discussion, each user was asked to identify one or more tasks that they personally encounter problems with performing for their work. Problem tasks were posted on the wall as they were identified so that everyone could see them. After everyone had identified tasks, the moderator read back through the list of tasks and the users were asked to indicate (by raising a hand) tasks that they often encounter problems with. This was done to find out which tasks out of the list were problems common to many of the people. The top several tasks were then planned to be discussed to find out specifics about the problems related to grasping, holding, squeezing or fine finger manipulation that users encountered with the tasks.

The session was scheduled to last for a total of 2 hours. The pre-identified tasks would be discussed first and would be followed by discussion of the top user-identified problems if time permitted. If the discussion of the pre-identified tasks generated a healthy discussion, then it would take up most of the allotted time. This would most likely generate a good result to the focus group session and allow identification of one or more tasks that would be suitable for the design study. However, if the pre-selected topics did not generate healthy discussion, the intent of the second part of the focus group was to allow members to identify troublesome work tasks and to discuss them as much as

possible. This would potentially allow a suitable task for the design study to be identified in the second part of the focus group session. It would also identify specific topics that could be discussed if a second focus group session was necessary.

A.4.5 Results

The discussion of the pre-identified tasks took up the majority of the time allotted. Users encountered a wide range of problems with the three pre-selected tasks. For each task, problems identified during the discussion included:

- Computer peripherals:
 - Hard to read labels
 - Difficult to see and to access ports
 - Cables are difficult to insert into ports that are angled
 - Difficulty aligning plugs
 - Difficulty removing plugs
- Packaging boxes for mailing
 - Holding down the box so that it doesn't slide around to get started taping it closed was identified as the biggest issue
 - Boxes were very difficult to tape closed
 - Dispenser is heavy/bulky
 - Dispenser is not intuitive to use
 - Some users were unable to use a tape dispenser by themselves
 - It was difficult for users to get the tape started again if it got stuck flat back down onto the roll of tape

- Sticky labels were difficult to pull off the backing. Once the label started coming off it was easy to remove from the backing, but getting started was very difficult
- Filing Documents
 - Cabinet drawers with drawer locks are difficult to open and require two hands
 - Labels on files in top drawers cannot be seen by some users
 - Labels are difficult to put onto folders so that they are straight
 - Labels that are put into plastic, transparent tabs: The labels could not be inserted into the tabs by most users
 - Locating a specific file is difficult
 - It is hard to grasp individual folders to remove them
 - File folders that hang in a file drawer are easier to get to than ones that do not hang because the hanger part can be grabbed more easily
 - Files are hard to insert and remove for many focus group members without spilling the contents of the file

Along with the problems with the tasks, users were asked about ways that the problems they encountered might be solved. They were also asked to talk about ways that they already work around some of the problems. For each task:

- Computer peripherals:
 - Vertical ports allowing the USB connector to be inserted vertically on the top of the computer would make things much easier
 - Some users use a long USB extension cable. One end is always plugged into the computer and the other is kept in an easily accessible location

- Some other users utilize a USB hub that provides the accessibility of the cable solution but allows more devices to be connected
- Packaging boxes for mailing
 - Tape that is pre-cut (or perforated) to set lengths might make dispensing easier
 - Most users have others pack boxes, such as paying someone at the UPS store a few dollars to do it for them, when they need to do this task
- Filing documents
 - A file drawer that opens automatically like a cd tray on a computer would make opening and closing easier for most users
 - Some users have experience using lateral files. This way of storing files was much easier for these users with dexterity limitations

The final part of the focus group identified some additional tasks that users encounter problems performing. The tasks were not discussed, but the last minutes of the focus group session was used to ask participants about other tasks that they experience problems with. A list was made of additional issues and then focus group members were asked to indicate the most serious of the listed issues by raising their hands. The most serious of the additional issues encountered by the focus group participants were:

- Using scissors (5 participants indicated problems with this)
- Pouring and carrying liquids (5 participants indicated problems with this)
- Loading paper into machines, such as fax machines, that require the user to hold up a cover and then put it back down or placing papers into a slot (4 participants indicated problems with this)

- Copying odd sized documents with a copy machine (3 participants indicated problems with this): they encounter problems seeing the control menu so that the copier can be set to copy correctly

A number of other issues were identified. Some of these issues were also shared by more than one focus group member, but they were not identified by the group as the biggest issue that they encounter:

- Using hand tools that require repetitive motions
- Removing staples from documents so that they can be re-organized
- Opening envelopes – this is difficult even when using a letter opener
- Stocking shelves in a retail store
- Using a can opener – it is difficult to disconnect the can opener after the can is opened
- Opening and closing binders – inserting paper is easy but closing the binder again is very difficult
- Using a 3 hold punch or stapler – difficult to use manual ones because the handle might snap back up before the holes have been completely punched or all papers have been stapled.

A.4.6 Discussion

The first task discussed was that of connecting peripheral USB devices to a computer. Focus group members experienced many problems with this task. However, most of the problems described seemed to be related to the specifics of how the USB interface on specific computer cases was designed. For example, an angled USB port was very difficult to use. In this case, users would experience fewer problems if the USB port was

simply not angled or placed in a different location. One participant noted not experiencing many of the problems discussed when using a Macintosh notebook simply because the USB port is easily accessible.

Participants described the use of many work arounds that they use for connecting peripherals to computer. Some participants make use of USB hubs where the hub where one cable always connects the hub to the computer and allows them to place the hub itself in an easily accessible location. Other participants simply use a long USB cable where one end stays connected to the computer and the other end is place in an accessible location. The aim of the future design study is not to re-design an existing product or interface (which would be more of a universal design problem), but to design an Assistive Technology product for a specific task. Many of the problems related to connecting peripherals seemed to be related to the specifics of how the USB interface on the computer case was designed and so aren't good candidates for the design study.

One issue not specifically related to a specific computer case design is the problem of determining which side of a USB plug is the top and which is the bottom. It is necessary to know this so that plugs can be inserted correctly into the port. A product that could allow users to more easily tell the top of a USB plug from the bottom and then help them align it with the port properly could be useful. However, there was not much discussion about this issue except that it is hard to tell top from bottom to insert it correctly into the plug. There were also few ideas about how the situation might be improved. The discussion did not provide much detail on the problem of aligning plugs so it would not likely be suitable for the design study (since a small amount of input from users during design would not likely produce much impact on the design process).

The next task discussed was the task of packing boxes. Of all the tasks, this is the one where users really did not seem to have any existing work arounds or solutions for the problems they encountered. This task presented many problems for focus group participants and each problem generated much discussion. For example, many participants experienced problems with the box sliding around, which made it difficult to get started with taping it closed. Some participants loaded boxes with heavy items just to help keep it still for taping even though it was difficult for some participants to place the heavier items in the box in the first place. Even if the box remained still, there were further difficulties with taping. Participants found that the tape dispensers were difficult to use, bulky and confusing. Operating them sometimes required two people. Cutting the tape was difficult as well, with one resorting to trying to cut off a length of tape using their teeth.

There was good discussion on the specific problems related to the task and on ideas that might solve some of them. Packaging stood out from the other tasks discussed during the focus group because it was the only task where users almost totally relied on other people to do it for them. Existing tools available for packing a box seem to make the task so difficult for users with limited dexterity that they avoid it completely. It is a task that generated a lot of discussion of specific problems. There are also many different dimensions to the problem that do not necessarily have obvious solutions. This combination would make an ideal design task.

Finally, the task of filing documents was discussed. This discussion highlighted many problems and some ideas for solutions. Most of the solutions that participants discussed for correcting problems focused on new types of filing cabinets/systems. The types of filing systems that already exist are common and in wide use. Designing a new type of filing system might be nice but wouldn't likely represent a practical solution to the

problems experienced (unless all of the existing filing systems in the world were replaced, of course).

The many problems with filing experienced by focus group members, however, present a second possible task for the design study. The biggest problem identified by the users was in accessing the files themselves. Instead of a focus on the filing system itself, a design task that focuses on developing a device that allows users locate, select and retrieve a file from existing filing systems could be an appropriate challenge. Most of the focus group comments detailed many specific issues related to filing which indicates that the level of input to a design team would be good. There are also multiple dimensions to the problem that are common to all filing systems. The problem might have many potential design solutions and two different design teams would not be likely to come up with similar solutions to the problem. If the problem were more one-dimensional, different design teams might come up with very similar solutions which would make the impact of user input difficult to measure (which would be bad for the design study).

A.4.7 Conclusion

The best task to select for the design study would be a task that has several problems and potential for a variety of solutions. From the focus group input, the first choice task for the design study is to have the design teams design a product that will allow users with limited dexterity to be able to secure a box so that it can be packed and taped closed. An alternate choice for the design team task would be to have the teams design a device that allows users with limited dexterity to be able to locate, select, and remove/replace file folders from a filing system.

APPENDIX B

STUDY DESIGN BRIEF

Problem

People with dexterity limitations face many challenges. A dexterity limitation is a condition that causes a person to have reduced fine motor coordination that affects grasping, holding, reaching, squeezing or fine finger manipulation in one or both hands. These conditions can make it difficult, or even impossible, to use common devices to perform everyday tasks. Weakness, paralysis, pain, tremor and spasticity are some reasons for dexterity limitations.

The goal of this project is to design a device that will allow a person with limited dexterity to independently pack and tape closed a box. The device should meet the following specifications and solve several specific problems encountered by users:

- 1) The solution should be compatible with traditional 4-flap corrugated boxes that have been pre-formed and have only a single open side that must be sealed.
- 2) Box stability – Boxes tend to slide around while they are being loaded or sealed. The device should be able to prevent boxes of different sizes (from 8in long by 8in wide by 6in high up to 24in long by 24in wide by 24in high) from sliding while being loaded or taped closed.
- 3) Taping mechanism – Applying tape can be very difficult for users with limited dexterity. The device should provide a mechanism that allows users with limited dexterity to apply tape to a box in a way that is easy and accurate.
- 4) Independent use – The device should allow a user with limited dexterity to pack and tape closed a box independently without assistance from others.
- 5) Total cost – The total cost for materials that make up the device should not exceed \$60.

The environment that this device is targeted for is a small corporate office environment. The device would not necessarily be used constantly (such as in a busy, dedicated mail room), but it would see more moderate use (perhaps a few times per day). It should be sturdy and easy to move. The device should be effective at solving the problems above and performing the task well. It should also be satisfying for end users to use. For satisfaction, the device should be easy, comfortable and safe to use. It should also be aesthetically pleasing and since it is a device to aid users with dexterity limitations, it should be socially acceptable (i.e. it should not draw unwanted attention to a user's condition).

Milestones and Deliverables

The design process will be divided into three distinct stages: Concept Design, System Design and Detail Design. Your design team will be responsible for certain deliverables at the end of each of each stage.

- Concept design – Concept design will take place during a single session. Your team will develop a concept for the device and will be responsible for producing and turning in concept drawings by the end of the session.
- System design – System design will begin immediately the day after concept design. Your team will have 5 calendar days to build a rough working prototype of the device that was developed during concept design. It is recommended that each team member work approximately 2 hours per day during this phase. It may take individual teams a bit more or less time than this, but the prototype will likely require this amount of time to complete (in other words, 10 hours of work per team member for a total of 20 hours combined for the team) to complete successfully. The design does not need to look nice at the end of this stage, but it should be basically functional.

Detail design – Detail design will begin the day after the rough prototypes are turned in. Your team will have 5 days to make final revisions and refinements to the rough prototype. Again, 2 hours per day is recommended for this phase (in other words, 10 hours of work per team member for a total of 20 hours combined for the team). By the end of this phase, a fully finished and functional prototype that can be operated by an end user should be delivered. Your team should also deliver detailed technical drawings that describe how to fabricate and assemble the prototype along with a product.

APPENDIX C

DEXTERITY INFORMATION PROVIDED TO DESIGN TEAMS

Information about Dexterity Limitations

What is Dexterity

Dexterity covers the ability to grasp and hold objects, and to perform fine finger movements to manipulate small objects. The term dexterity is commonly applied to the use of fine motor skills of the hands and fingers. Fine motor skills are skills that involve a refined use of the small muscles controlling the hand, fingers, and thumb that allow one to perform activities of daily living. Some examples of activities of daily living include:

- Bathing
- Dressing and undressing
- Eating
- Preparing meals
- Taking medications
- Using the telephone

Dexterity Functions

A single hand can be used to perform functions that allow interaction with products.

These critical functions are:

- Push force – This is where the fingers or palm are used to exert a force without grasping.

- Pinch (precision) grip – This is the ability to develop opposable forces between the thumb and fingers of the hand.
 - finger pad or lateral aspect used for contact
 - Thumb opposition
 - Use extrinsic & intrinsic movements

- Power grip – This grip is formed by the thumb, all four fingers and the palm of the hand. It is less precise than a pinch grip, but the large number of muscles used means that large forces can be generated with comparatively little effort.
 - Fingers flexed around object; separated from palm
 - Large contact area
 - Use extrinsic movements

Many products require the use of both hands at the same time. In some cases, this is unnecessary and an alternate design can allow the product to be used one handed. The ability to use a product one handed typically reduces design exclusion and increases user satisfaction.

Some common design guidelines

- Controls requiring simultaneous movements in different directions (like combined pushing and twisting) are especially difficult for those with reduced motor control.
- Easier gripping can be facilitated by providing a slightly deformable surface and maximizing the available contact area.
- Ensure that the product can be used left or right handed as well as one or two handed.

- Gripping tasks should be arranged so that they can be performed with the wrist in a neutral and straight position in order to improve comfort and minimize pain for those with conditions such as arthritis.
- Provide loops, handles or sudden changes in surface contours to help minimize the gripping strength required.
- Avoid connection slots that require both vision and dexterity to align.

Hand Grips

[Image showing various grips: Tip pinch, key pinch span, disc, hook, power, flat hand push, finger push]

Hand Movements

[Image illustrating various hand movements: Adduction, Neutral, Abduction and Apposing and opposing.]

Wrist Movements

[Image illustrating flexion and extension movements of the wrists.]

[Image illustrating ulnar and radial deviation.]

Forearm movements

[Illustration showing supination and pronation of the forearm.]

Muscles of the hand

[Image illustrating the location of extrinsic and intrinsic muscles of the arm and hand.]

[Image illustrating the location of extensor and flexor muscles.]

[Image illustrating the location of dorsal and volar muscles of the hand.]

Hand deformities common to arthritis

[Image illustrating ulnar drift.]

[Image illustrating Boutonniere deformity.]

[Image illustrating Swan Neck deformity.]

Hand paralysis and contracture

[Image illustrating hand paralysis with contracture.]

APPENDIX D

DESIGNER RECRUITMENT FLIER

The Center for Assistive Technology and Environmental Access (CATEA) is looking for design students to participate in a design study. The study will investigate the effect of input during the process of designing an Assistive Technology (AT) product. In this study, 8 teams each made up of two members will be tasked to develop a concept to address a real world problem related to a specific limitation and produce a functioning prototype. Some details of the study include:

- Any Ga. Tech junior or senior design student may apply to participate
- Design activities from start to finish will be divided over 11 days
- You will be compensated for your time up to a total of \$224
- Each design team will be provided \$60 for materials

If you are interested in participating or have any questions, please contact Young Mi Choi:

removed@mail.gatech.edu

APPENDIX E

DESIGNER SCREENING SURVEY

1. Do you have any type of functional limitation (ie, do you difficulty hearing even with a hearing aid, do you have difficulty seeing even with glasses/contacts etc)?
☐ Yes ☐ No

2. Have you ever designed a product to solve a problem specifically for a person with a disability?
☐ Yes ☐ No

If Yes, please briefly describe the product you designed and why you designed it (ie, was it for a class?).

3. Do you have any close family members or close friends (that is family or friends that you have spent a **significant** amount of time with) who suffer from a disability?
☐ Yes ☐ No

4. What was your design studio grade from the previous semester?

5. Do you hold a job outside of school?

APPENDIX F

ADDITIONAL INSTRUCTIONS GIVEN TO EACH DESIGN TEAM

F.1 Instructions given to No Additional Input – Team 1

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.
- Research Materials – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief and the additional information about dexterity limitations. Your team **may not** perform any other types of research activities. This includes :
 - conducting research online (websites, blogs, chat, etc)
 - conducting research in a library
 - the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
 - seeking input from professional therapists
 - seeking input from people with a dexterity limitation
 - seeking direct or indirect input from any outside source

If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any other source.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The ID Shop

Your team will perform shop work in the ID shop. All of your fabrication work for the study should be performed in the ID shop and follow the ID shop policies.

Schedule

- Concept Design Phase – Concept design will take place on February 26, 2009 from 4pm-8pm. At the end of the concept design phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Concept Design (on February 27) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in ID Shop.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

Detail Design Phase – Detail design will begin immediately following System Design (on February 4) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task. She will also coordinate the time and place to turn in deliverables for each phase.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.2 Instructions given to No Additional Input – Team 2

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.
- Research Materials – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief and the additional information about dexterity limitations. Your team **may not** perform any other types of research activities. This includes :
 - conducting research online (websites, blogs, chat, etc)
 - conducting research in a library
 - the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
 - seeking input from professional therapists
 - seeking input from people with a dexterity limitation
 - seeking direct or indirect input from any outside source

If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any other source.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The CATEA Shop

- Your team will perform shop work in the CATEA shop. Since some of the available equipment in the CATEA shop is different from the ID shop, there will be a short orientation before you begin System Design. All of your shop work (during System and Detail design) must be done in the CATEA shop. The one exception to this is that you may use the ID shop only if a piece of equipment that you need is not available in the CATEA shop, and then only for as long as necessary to use that equipment. While not working on the design, all work must be stored in Young Mi's office on the first floor at CATEA room 102.

Note: If you must utilize the ID shop at some point, it is possible that you may run into another team that is also part of the study. You may not be sure of since participants shouldn't be talking with others outside their team about the study. However, if you suspect that they are, do not talk with them about the study (obviously) but most importantly, do not try to get ideas about what the other team is doing to use in your own design (since this would contaminate the results of the study).

The CATEA shop is open and available anytime during regular business hours (9am-6pm). If you need access to the shop after hours this can easily be arranged. Let Young Mi know the hours that you plan to use the shop in advance (as much ahead of time as possible). This will be necessary to make you have access (if you want to work in the evening) and to make sure that safety procedures are followed. For safety, either both design team members must work in the shop at the same time, or if only one team member will be working in the shop outside of regular hours, you will need to contact Young Mi so that she can be present (basically, nobody should ever work in the shop alone).

Schedule

- Concept Design Phase – Concept design will take place on March 22, 2009 from 10am-2pm. At the end of the concept design phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Concept Design (on March 23) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in CATEA's Shop, so you will need to purchase any necessary materials and bring them to CATEA.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It

is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

Detail Design Phase – Detail design will begin immediately following System Design (on March 28) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task. She will also coordinate the time and place to turn in deliverables for each phase.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should

contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.3 Instructions given to Tool Input – Team 1

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

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Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific

details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.

- **Input From Tools and Simulation** - Your team will be able to use tools to simulate conditions experienced by people with dexterity limitations. Your job in this study is to use these tools to help you produce a design concept and prototype that will be the best possible solution for the end user (in terms of both effectiveness and satisfaction). Your team will be provided with simulation tools that will be available for your use throughout the entire study.
- **Research Materials** – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and through the use of the provided simulation tools.

Your team **may not** perform any other types of research activities. This includes :

- conducting research online (websites, blogs, chat, etc)
- conducting research in a library
- seeking input from professional therapists
- seeking input from people with a dexterity limitation
- seeking direct or indirect input from any outside source

The type of input your team will be getting via simulation tools. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any other source.

- **Milestones and Deliverables** – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi

(Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.

- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The CATEA Shop

- Your team will perform shop work in the CATEA shop. Since some of the available equipment in the CATEA shop is different from the ID shop, there will be a short orientation before you begin System Design. All of your shop work (during System and Detail design) must be done in the CATEA shop. The one exception to this is that you may use the ID shop only if a piece of equipment that you need is not available in the CATEA shop, and then only for as long as necessary to use that equipment. While not working on the design, all work must be stored in Young Mi's office on the first floor at CATEA.

Note: If you must utilize the ID shop at some point, it is possible that you may run into another team that is also part of the study. You may not be sure of since participants shouldn't be talking with others outside their team about the study. However, if you suspect that they are, do not talk with them about the study (obviously) but most importantly, do not try to get ideas about what the other team is doing to use in your own design (since this would contaminate the results of the study).

The CATEA shop is open and available anytime during regular business hours (9am-6pm). If you need access to the shop after hours this can easily be arranged. Let Young Mi know the hours that you plan to use the shop in advance (as much ahead of time as possible). This will be necessary to make you have access (if you want to work in the evening) and to make sure that safety procedures are followed. For safety, either both design team members must work in the shop at the same time, or if only one team member will be working in the shop outside of regular hours, you will need to contact Young Mi so that she can be present (basically, nobody should ever work in the shop alone).

Schedule

- Concept Design Phase – Concept design will take place on February 14, 2009 from 10am-2pm. You will be provided with a set of simulation tools at the beginning of the concept design sessions that you will be allowed utilize for the duration of the study. At the end of the concept design phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Concept Design (on February 15) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in CATEA's Shop, so you will need to purchase any necessary materials and bring them to CATEA.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on February 20) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design.
- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task. She will also coordinate the time and place to turn in deliverables for each phase.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call

anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.4 Instructions given to Tool Input – Team 2

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

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Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester

so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.

- **Input From Tools and Simulation** - Your team will be able to use tools to simulate conditions experienced by people with dexterity limitations. Your job in this study is to use these tools to help you produce a design concept and prototype that will be the best possible solution for the end user (in terms of both effectiveness and satisfaction). Your team will be provided with simulation tools that will be available for your use throughout the entire study.
- **Research Materials** – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and through the use of the provided simulation tools.

Your team **may not** perform any other types of research activities. This includes :

- conducting research online (websites, blogs, chat, etc)
- conducting research in a library
- seeking input from professional therapists
- seeking input from people with a dexterity limitation
- seeking direct or indirect input from any outside source

The type of input your team will be getting via simulation tools. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any other source.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The ID Shop

Your team will perform shop work in the ID shop. All of your fabrication work for the study should be performed in the ID shop and follow the ID shop policies.

Schedule

- Concept Design Phase – Concept design will take place on April 1, 2009 from 3:30pm-7:30pm. You will be provided with a set of simulation tools at the beginning of the concept design sessions that you will be allowed utilize for the duration of the study. At the end of the concept design phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Concept Design (on April 2) and last for 5 days. During this time, your team will be

responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in the ID shop.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on April 7) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design.
- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task. She will also coordinate the time and place to turn in deliverables for each phase.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.5 Instructions given to OT Input – Team 1

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.
- Professional Input - Your team will receive input from an Occupational Therapist (OT) during the Concept and Detail Design phases of the study. As a design team, your job will be to ask questions and learn all you can to aid your design. The OT is a source of expert knowledge about the capabilities and troubles that end users face. While providing input, the OT should be considered part of the team. This input should be used to help you produce a design concept and prototype that will be the best possible solution for the end user (in terms of both effectiveness and satisfaction). But keep in mind, the OT is not a designer, so you may need to imagine many design solutions and work with the OT to identify and refine the best ideas. Since the effect of these input sessions are the object of this study, it is important to actually use the input and incorporate it into your design solution as much as possible.
- Research Materials – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and any information provided through input from the

OT for the design. Your team **may not** perform any other types of research activities. This includes :

- conducting research online (websites, blogs, chat, etc)
- conducting research in a library
- the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
- seeking input from people with a dexterity limitation

The type of input your team will be getting is from a professional OT. Your goal will be to learn as much as you can from the OT to create the best possible solution for the end user. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any external source other than the OT.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The ID Shop

Your team will perform shop work in the ID shop. All of your fabrication work for the study should be performed in the ID shop and follow the ID shop policies.

Schedule

- Concept Design Phase – Concept design will take place on February 14, 2009. The OT will arrive at CATEA to work with your team on the development of your product concept from 10am-2pm. At the end of the phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Detail Design (on February 15) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in CATEA's Shop, so you will need to purchase any necessary materials and bring them to CATEA.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on February 20) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design. You will

receive input from the OT again twice during this phase. Except for the input sessions with the OT, the specific work schedule for this phase is up to the design team members, as before.

The input from the OT will be on:

- the first day of detail design (February 20)
- and the third day of detail design (February 22)

These two sessions will each last for 2 hours. Young Mi will help coordinate these ahead of time to help match up everybody's schedules. For the first input session will be to allow the OT to evaluate the prototype and allow you to work together to define refinements and updates to the prototype (this is why having a rough working prototype completed is important). The goal of the second session is to get final input on any changes that may have been made.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call

anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.6 Instructions given to OT Input – Team 2

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the

study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.

- Professional Input - Your team will receive input from an Occupational Therapist (OT) during the Concept and Detail Design phases of the study. As a design team, your job will be to ask questions and learn all you can to aid your design. The OT is a source of expert knowledge about the capabilities and troubles that end users face. While providing input, the OT should be considered part of the team. This input should be used to help you produce a design concept and prototype that will be the best possible solution for the end user (in terms of both effectiveness and satisfaction). But keep in mind, the OT is not a designer, so you may need to imagine many design solutions and work with the OT to identify and refine the best ideas. Since the effect of these input sessions are the object of this study, it is important to actually use the input and incorporate it into your design solution as much as possible.
- Research Materials – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and any information provided through input from the OT for the design. Your team **may not** perform any other types of research activities. This includes :
 - conducting research online (websites, blogs, chat, etc)
 - conducting research in a library

- the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
- seeking input from people with a dexterity limitation

The type of input your team will be getting is from a professional OT. Your goal will be to learn as much as you can from the OT to create the best possible solution for the end user. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any external source other than the OT.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The CATEA Shop

- Your team will perform shop work in the CATEA shop. Since some of the available equipment in the CATEA shop is different from the ID shop, there will be a short orientation before you begin System Design. All of your shop work (during System and Detail design) must be done in the CATEA shop. The one exception to this is that you may use the ID shop only if a piece of equipment that

you need is not available in the CATEA shop, and then only for as long as necessary to use that equipment. While not working on the design, all work must be stored in Young Mi's office on the first floor at CATEA.

Note: If you must utilize the ID shop at some point, it is possible that you may run into another team that is also part of the study. You may not be sure of since participants shouldn't be talking with others outside their team about the study. However, if you suspect that they are, do not talk with them about the study (obviously) but most importantly, do not try to get ideas about what the other team is doing to use in your own design (since this would contaminate the results of the study).

The CATEA shop is open and available anytime during regular business hours (9am-6pm). If you need access to the shop after hours this can easily be arranged. Let Young Mi know the hours that you plan to use the shop in advance (as much ahead of time as possible). This will be necessary to make you have access (if you want to work in the evening) and to make sure that safety procedures are followed. For safety, either both design team members must work in the shop at the same time, or if only one team member will be working in the shop outside of regular hours, you will need to contact Young Mi so that she can be present (basically, nobody should ever work in the shop alone).

Schedule

- Concept Design Phase – Concept design will take place on April 1, 2009. The OT will arrive at CATEA to work with your team on the development of your product concept from 5:30pm-9:30pm. At the end of the phase, your team will be responsible for identifying a concept for further development and turning in

detailed sketches of the concept. You may also create study models during this phase if desired.

- System Design Phase – System design will begin immediately after Detail Design (on April 2) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in CATEA's Shop, so you will need to purchase any necessary materials and bring them to CATEA.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on April 7) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design. You will receive input from the OT again twice during this phase. Except for the input sessions with the OT, the specific work schedule for this phase is up to the design team members, as before.

The input from the OT will be on:

- the first day of detail design (April 7)
- and the third day of detail design (April 9)

These two sessions will each last for 2 hours. Young Mi will help coordinate these ahead of time to help match up everybody's schedules. For the first input session will be to allow the OT to evaluate the prototype and allow you to work together to define refinements and updates to the prototype (this is why having a rough working prototype completed is important). The goal of the second session is to get final input on any changes that may have been made.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.7 Instructions given to User Input – Team 1

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a

chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.

- **User Input** - Your team will receive direct input from potential end users during the Concept and Detail Design phases of the study. As a design team, your job will be to ask questions and learn all you can about their capabilities, troubles and potential solutions that can be used in your design. While providing input, the users should be considered part of the team. This input should be used to help you produce a design concept and prototype that will be the best possible solution for them (in terms of both effectiveness and satisfaction). But keep in mind, the users are not designers, so you may need to imagine many design solutions and work with them to identify and refine the best ideas. Since the effect of these input sessions are the object of this study, it is important to actually use the input and incorporate it into your design solution as much as possible.
- **Research Materials** – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and any information provided through input from the users for the design. Your team **may not** perform any other types of research activities. This includes :
 - conducting research online (websites, blogs, chat, etc)
 - conducting research in a library
 - the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
 - seeking input from professional therapists
 - seeking input from people outside of the study with a dexterity limitation
 - seeking direct or indirect input from any other outside source

The type of input your team will be getting is from end users. Your goal will be to learn as much as you can from them to create the best possible solution. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any source other than the users during the input sessions.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by 10 real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The CATEA Shop

- Your team will perform shop work in the CATEA shop. Since some of the available equipment in the CATEA shop is different from the ID shop, there will be a short orientation before you begin System Design. All of your shop work (during System and Detail design) must be done in the CATEA shop. The one exception to this is that you may use the ID shop only if a piece of equipment that you need is not available in the CATEA shop, and then only for as long as necessary to use that equipment. While not working on the design, all work must be stored in Young Mi's office on the first floor at CATEA room 102.

Note: If you must utilize the ID shop at some point, it is possible that you may run into another team that is also part of the study. You may not be sure of since participants shouldn't be talking with others outside their team about the study. However, if you suspect that they are, do not talk with them about the study (obviously) but most importantly, do not try to get ideas about what the other team is doing to use in your own design (since this would contaminate the results of the study).

The CATEA shop is open and available anytime during regular business hours (9am-6pm). If you need access to the shop after hours this can easily be arranged. Let Young Mi know the hours that you plan to use the shop in advance (as much ahead of time as possible). This will be necessary to make you have access (if you want to work in the evening) and to make sure that safety procedures are followed. For safety, either both design team members must work in the shop at the same time, or if only one team member will be working in the shop outside of regular hours, you will need to contact Young Mi so that she can be present (basically, nobody should ever work in the shop alone).

Schedule

- Concept Design Phase – Concept design will take place on February 28, 2009.

The users will arrive at CATEA to work with your team on the development of your product concept from 10am-2pm. At the end of the phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.

- System Design Phase – System design will begin immediately after Concept Design (on March 1) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in CATEA's Shop, so you will need to purchase any necessary materials and bring them to CATEA.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on March 6) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design. You will receive input from users again twice during this phase. Except for the input sessions with the users, the specific work schedule for this phase is up to the design team members, as before.

The input from the users will be on:

- the first day of detail design (March 6)
- and the third day of detail design (March 8)

These two sessions will each last for 2 hours. Young Mi will help coordinate these ahead of time to help match up everybody's schedules. For the first input session will be to allow the users to evaluate the prototype and allow you to work together to define refinements and updates to it (this is why having a rough working prototype completed is

important). The goal of the second session is to get final input on any changes that may have been made.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

F.8 Instructions given to User Input – Team 2

Purpose of the Study

The purpose of this study is to measure the effect that different types of input during design of an Assistive Technology (AT) product have on the finished product. As you know, there are many important uses for input during design because, among other

things, it is helpful in learning about a design problem. Past design studies have investigated many different aspects of user input, but it turns out that none has actually measured how much they actually impact the final product. That is the challenge of this study.

I have a feeling that a study like this hasn't been done yet because it is a **hard** thing to measure. This is because there are a lot of different activities going on during the course of any design project. This basically creates noise that makes it hard to pinpoint which activities actually impact the design, how they impact it and how much. The purpose of the instructions below is intended to reduce this noise as much as possible, so it is very important to follow them closely.

Additional Instructions and Procedures

- Do not discuss the study with anyone that is not part of your design team or who is not a member of the study's staff. It is very important for the outcome of the study that none of the design teams that are involved communicate with each other. Teams will be participating in this study over the majority of the semester so it is also important that any future participants **not** know about the specific details (like the design task, milestones, etc) until the first day that they begin the study. This restriction is not for secrecy in and of itself. If participants have a chance to consider some of the details beforehand, it can make the effect of input on the final design (which is the purpose of the study) impossible to measure.
- User Input - Your team will receive direct input from potential end users during the Concept and Detail Design phases of the study. As a design team, your job will be to ask questions and learn all you can about their capabilities, troubles and potential solutions that can be used in your design. While providing input, the users should be considered part of the team. This input should be used to help

you produce a design concept and prototype that will be the best possible solution for them (in terms of both effectiveness and satisfaction). But keep in mind, the users are not designers, so you may need to imagine many design solutions and work with them to identify and refine the best ideas. Since the effect of these input sessions are the object of this study, it is important to actually use the input and incorporate it into your design solution as much as possible.

- Research Materials – In order to measure the intended variables in this study, certain research activities that you might normally perform are restricted. Your team may utilize the information in the design brief, the additional information about dexterity limitations and any information provided through input from the users for the design. Your team **may not** perform any other types of research activities. This includes :
 - conducting research online (websites, blogs, chat, etc)
 - conducting research in a library
 - the use of any external aid to try to simulate a dexterity limitation (like wearing gloves, taping fingers together, etc)
 - seeking input from professional therapists
 - seeking input from people outside of the study with a dexterity limitation
 - seeking direct or indirect input from any other outside source

The type of input your team will be getting is from end users. Your goal will be to learn as much as you can from them to create the best possible solution. If you were to utilize any other method to learn about the design problem, it would make it impossible to which type of input had an effect on your design. The use of study models is perfectly fine, but you should not attempt to get information from any source other than the users during the input sessions.

- Milestones and Deliverables – The deliverables for each phase will be turned in at CATEA, since most of the will be performed there. Young Mi Choi (Christina.choi@gatech.edu) will be in contact with you throughout the study and will work with you on the details.
- Evaluation – After the design phase of the study, your prototype will be used and evaluated by 10 real end users. So, it is important for the device to work and to be sturdy. The prototype will be evaluated for effectiveness and satisfaction. So, keep this in mind during design. Your prototype should be the best possible solution to the design problem that you can create for users with limited dexterity, and implemented in a way that is satisfying and as socially acceptable as it can be.

The ID Shop

Your team will perform shop work in the ID shop. All of your fabrication work for the study should be performed in the ID shop and follow the ID shop policies.

Schedule

- Concept Design Phase – Concept design will take place on March 22, 2009. The users will arrive at CATEA to work with your team on the development of your product concept from 11am-3pm. At the end of the phase, your team will be responsible for identifying a concept for further development and turning in detailed sketches of the concept. You may also create study models during this phase if desired.
- System Design Phase – System design will begin immediately after Concept Design (on March 23) and last for 5 days. During this time, your team will be responsible for building a rough working prototype of your concept design. It

doesn't need to be pretty for this phase, but it should function as intended. All fabrication work during this phase must be done in the ID shop.

The schedule for this phase is flexible. You may work anytime that is convenient. Your team may work together, divide tasks and work separately or a combination of the two. It is suggested that each team member spend 2 hours per day for this phase, though you can choose to work more or less than this. Your team should have a working version of the prototype finished at the end of 5 days, so it is strongly recommended to spread out the design work as much as possible.

- Detail Design Phase – Detail design will begin immediately following System Design (on March 28) and last for 5 days. It is again suggested that each design team member spend about 2 hours per day on Detail Design. You will receive input from users again twice during this phase. Except for the input sessions with the users, the specific work schedule for this phase is up to the design team members, as before.

The input from the users will be on:

- the first day of detail design (March 28)
- and the third day of detail design (March 30)

These two sessions will each last for 2 hours. Young Mi will help coordinate these ahead of time to help match up everybody's schedules. For the first input session will be to allow the users to evaluate the prototype and allow you to work together to define refinements and updates to it (this is why having a rough working prototype completed is important). The goal of the second session is to get final input on any changes that may have been made.

- Young Mi will be in contact with you throughout the study to see how you are doing and to make sure that you have everything that you need to complete the design task.
- Each design team member will be provided with a small diary. The purpose of this diary is to keep track of the time that you spend working on the study. Each participant is asked to record the date, the time you started working and the time you stopped working on any activity related to the study. You also encouraged make any other notes such as what you are working on or challenges you encounter during design.

Contact information

It is very possible that these instructions do not cover all of the questions that you might have. If you have any problems or questions about the study, please contact Young Mi Choi by e-mailing Christina.choi@gatech.edu or by calling xxx-xxx-xxxx. You may call anytime of day 7 days a week. Some people like to work very late, and you should contact Young Mi at literally any time (seriously) if you need access to the shop, have questions or anything else related to the study.

APPENDIX G

STUDY COSTS

Pre-Focus group :

- 7 members * \$50 each = \$350

Pilot Study Design Team:

- 1 team * 2 members * \$224/member = \$448
- Reimbursement for materials to build prototype = \$60

Pilot Evaluation

- 1 user for 4 hours: \$80

Student Design Teams:

- 8 teams * 2 members/team * \$224/member = \$3584
- \$60 per team for materials to build their prototype = 8 * \$60= \$480

Users providing input to design teams:

The users provided input a total of 3 times to each of the two design teams. The first session was 4 hours and the next two were for 2 hours. The compensation was \$80 for the initial 4 hour session and \$50 for each of the two hour sessions for a total of \$180 per user for each team they provided input for.

- 3 users * \$180/team * 2 teams = \$1080

Users to evaluate designs:

8 total designs

Estimated time for evaluating each: 30 minutes

Required number of evaluations for each product: 20 (users)

Cost per user 3 hour evaluation session: \$60

- \$60/user * 20 users = \$1200 for design evaluation

Other expenses

- Pens, pencil, sketch paper: \$100
- Boxes, tape, packing materials: \$200

Grand total costs:

Pre-Focus group:	\$350
Pilot Study:	\$508
Pilot Evaluation:	\$80
Student design team:	\$4,064
Users to provide input:	\$1,080
Users to evaluate designs:	\$1,200
<u>Other Expenses:</u>	<u>\$300</u>
Total Cost:	\$7,582

APPENDIX H

DESIGN TEAM SCHEDULES AND LOCATIONS

Each of the eight student design teams performed the study independently from the other teams. During the study, two design teams performed the study in parallel at the same time in different facilities. Concept design sessions were all performed at CATEA with design teams working in different rooms. System and Detail design were performed in different shop locations on campus: the Industrial Design (ID) shop and the CATEA shop. The dates that each team performed each phase of design are below, followed by a graphical calendar illustration which shows where team schedules overlapped (yet still kept physically separate).

OT Input Team 1:

- Concept Design: February 14 - CATEA
- System Design: February 15-19 - ID Shop
- Detail Design: February 20-24 - ID Shop

Tool/Simulation Input Team 1:

- Concept Design: February 14 - CATEA
- System Design: February 15-19 - CATEA Shop
- Detail Design: February 20-24 - CATEA Shop

No Additional Input Team 1:

- Concept Design: February 26 - CATEA
- System Design: February 27-March 3 - ID Shop
- Detail Design: March 4-8 - ID Shop

User Input Team 1:

- Concept Design: February 28 - CATEA
- System Design: March 1-5 - CATEA Shop
- Detail Design: March 6-10 - CATEA Shop

No Additional Input Team 2:

- Concept Design: March 22 - CATEA
- System Design: March 23-27 - CATEA Shop
- Detail Design: March 28-April 1 - CATEA Shop

User Input Team 2:

- Concept Design: March 22 - CATEA
- System Design: March 23-27 - ID Shop
- Detail Design: March 6-10 - ID Shop

OT Input Team 2:

- Concept Design: April 1 - CATEA
- System Design: April 2-6 - CATEA Shop
- Detail Design: April 7-11 - CATEA Shop

Tool/Simulation Input Team 2:

- Concept Design: April 1 - CATEA
- System Design: April 2-6 - ID Shop
- Detail Design: April 7-11 - ID Shop

2/8/2009 - 4/25/2009						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
February 8	9	10	11	12	13	14
						Phase: Concept Design Team: First OT Input Team
						Phase: Concept Design Team: First Simulation Team
15	16	17	18	19	20	21
Phase: System Design Team: First OT Input Team Location: ID Shop						
Phase: System Design Team: First Simulation Team Location: CATEA Shop						
22	23	24	25	26	27	28
Phase: Detail Design Team: First OT Input Team Location: ID Shop				Phase: Concept Design Team: First No Input Team	Phase: System Design Team: First No Input Team Location: ID Shop	
Phase: Detail Design Team: First Simulation Team Location: CATEA Shop						Phase: Concept Design Team: First End User Input Team
March 1	2	3	4	5	6	7
Phase: System Design Team: First No Input Team Location: ID Shop			Phase: Detail Design Team: First No Input Team Location: ID Shop			
Phase: System Design Team: First End User Input Team Location: CATEA Shop						
8	9	10	11	12	13	14
Phase: Detail Design Team: First End User Input Team Location: CATEA Shop						
15	16	17	18	19	20	21
			Spring Break			
22	23	24	25	26	27	28
Phase: Concept Design Team: Second No Input Team	Phase: System Design Team: Second No Input Team Location: CATEA Shop					
Phase: Concept Design Team: Second End User Input Team	Phase: System Design Team: Second End User Input Team Location: ID Shop					
29	30	31	April 1	2	3	4
Phase: Detail Design Team: Second No Input Team Location: CATEA Shop				Phase: System Design Team: Second OT Input Team Location: CATEA Shop		
Phase: Detail Design Team: Second End User Input Team Location: ID Shop			Phase: Concept Design Team: OT Input Team 2	Phase: System Design Team: Second Simulation Team Location: ID Shop		
			Phase: Concept Design Team: Simulation Team 2			
5	6	7	8	9	10	11
			Phase: Detail Design Team: Second OT Input Team Location: CATEA Shop			
			Phase: Detail Design Team: Second Simulation Team Location: ID Shop			
12	13	14	15	16	17	18
19	20	21	22	23	24	25
					Last Day of Classes	

Figure H.1 Illustration of design team activities within the academic calendar

APPENDIX I

PRODUCT EVALUATION SURVEY

The evaluation survey consisted of 13 total items. The first 12 were presented as a 5 item Likert scale. Items 1, 2, 9, 10 and 11 were focused on measuring the opinion of the product's effectiveness. The rest of the items were focused on gathering the opinion of various aspects of the level of satisfaction with the product. The final question on the survey asked the evaluator to provide an overall opinion of the product.

Individual survey questions:

1. I could easily complete the task with the device. :

This item is meant to measure the user's opinion of how easy it was to actually close the box using the device. It is a measure of effectiveness since a more effective product will generally be easier to use than a less effective one.

2. The device helped to keep the box stable so that it could be closed.

This item is included as it was identified by the pre-study focus group as one of the major problems that they encountered when closing a box. It was also included in the design brief specifically as a problem that the product needed to address. It is a measure of effectiveness since an effective product for users with limited dexterity will provide a solution to this problem.

3. It was easy to understand how to operate the device.
4. The device was comfortable to use.
5. Using the device was easy.

6. Using the device felt safe.

For questions 3-6: A user must be able to understand how the device is supposed to be operated. The device should also be comfortable and easy to use as well as safe. All of these are different aspects of satisfaction and should be included if measuring overall satisfaction with a product.

7. Aesthetically, I like the overall look of the device.

A device does not necessarily need to be aesthetically pleasing to be satisfactory. Although any AT devices are not necessarily designed with aesthetics as a high priority, aesthetics do play a role in product satisfaction.

8. As a 'disability' product, this device would draw un-wanted attention.

This item directly addresses the social acceptability of the design. This is an important aspect of satisfaction for AT products.

9. I think the idea behind how the device is meant to operate provides a good solution to problems I encounter in packing and taping closed a box.

This item gathers the user's opinion of the approach that the product takes to solving the problem. It was included to try to find out how good the user thought that the idea behind the product was (in other words, do they think it has potential) even if the specific implementation of the solution idea did not work well for them.

10. It was easier to close the box with the device than it was when using a 'standard' tape dispenser.

Each user will have evaluated a standard tape dispenser at the beginning of the evaluation part of the session. This item directly asks the user to compare the current product with the standard dispenser. Since there is no specific product solution for closing a box for users with limited dexterity, an effective design will allow the user to more easily complete the task than they would be able to do with a standard tape dispenser.

11. Compared to other products to aid with packing (that were not created in this study), the actual functionality of this product is better..

This question asks the user to rank the actual implementation of the design concept and how well it solved the problem of closing the box relative to other products they have used. This comparison specifically excludes any product created as part of this study. Combined with question 9, this can tell what the user thought of the idea and how well that idea was actually implemented by the product.

12. I would be happy to buy and use this device if it were available for sale.

A satisfactory product is one that an end user would ultimately purchase and use. The object of the study is not to product a commercialized product, however determining a user's willingness to purchase a product after trying it out is an indicator of their level of satisfaction (since a user would be unlikely to purchase a product that they know they would not be satisfied with).

13. Please mark the statement that most closely matches your overall opinion of the product.

This item asks the user to provide their overall opinion of the product. A user may have an overall good opinion of a product even if their opinions of certain aspects of it are low. This question will allow user's opinions of the of effectiveness and satisfaction to be compared to see if certain aspects of the products tend to contribute more or less to their overall opinion of the product.

This opinion can also be compared with the final ranking assigned by the user. For example, if a user rates the product as 'perfect' we would expect the corresponding score for effectiveness and satisfaction on the survey to be high. Similarly, the product ranking (where the user rates each product from best to worst after evaluating each) was compared with the analysis. Highly ranked products would be expected to have high

survey scores and will most frequently be regarded with a high overall opinion from the users.

The final interview questions were used to allow the user to highlight any additional issues they encountered with the products and were used to help better understand the survey analysis results.

The product evaluation survey:

Please mark your opinion to each of the following statements:

	Strongly disagree	Somewhat disagree	Neither Agree nor Disagree	Somewhat Agree	Strongly Agree
1. I could easily complete the task with the device.	1	2	3	4	5
2. The device helped to keep the box stable so that it could be closed.	1	2	3	4	5
3. It was easy to understand how to operate the device.	1	2	3	4	5
4. The device was comfortable to use.	1	2	3	4	5
5. Using the device was easy.	1	2	3	4	5
6. Using the device felt safe.	1	2	3	4	5
7. Aesthetically, I like the overall look of the device.	1	2	3	4	5
8. As a 'disability' product, this device would draw un-wanted attention.	1	2	3	4	5
9. I think the idea behind how the device is meant to operate provides a good solution to problems I encounter in packing and taping closed a box	1	2	3	4	5
10. It was easier to close the box with the device than it was when using a 'standard' tape dispenser.	1	2	3	4	5
11. Compared to other products to aid with packing (that were not created in this study), the actual functionality of this product is better.	1	2	3	4	5
12. I would be happy to buy and use this device if it were available for sale.	1	2	3	4	5

13. Please mark the statement that most closely matches your overall opinion of the product:

- () The product is very good, I like almost everything about it.
- () The product is mostly good and there are only a few things about it that I don't like.
- () The product is average, there are about as many things that I like as dislike
- () The product is mostly bad, I liked some aspects, but I disliked most things about it
- () The product is bad, I did not like anything about it

Each participant was asked two additional interview questions after completing the survey. The questions were:

- Please describe the aspect of the device that you liked the most.
- Please describe the aspect of the device that you dis-liked the most.

APPENDIX J

PILOT STUDY RESULTS

There were a number of outstanding questions after defining the initial study plan. Probably the biggest one was whether or not a student design team would be able to produce a working prototype. Perhaps the design problem would turn out to be much more complex than expected. It was also unclear if the durations for each of the design phases would be appropriate. The timing of input was another issue. Although the focus of the study is not about when a design team should receive input, it was still important to ensure that it is provided at appropriate points during the design process. If the direct input was not timed reasonably well, then it was less likely to have a strong influence on the design process which would make its impact more difficult to measure.

To answer these questions (and to test the materials and procedures), a pilot run of the study was conducted. It was conducted from January 19-29, 2009. A single design team was used for the pilot. The team was given input from an Occupational Therapist (OT). Direct input was used during the pilot so that issues related to the timing and dosage (which would apply to professionals or to users) could be investigated. The design teams and the OT kept diaries throughout the pilot. All participants were instructed to log the times that they started and stopped any work related to the pilot. The goal of this was primarily to measure how much time was actually spent working on the study by each participant. Participants were also asked to make notes of any thoughts or issues about the study that came to mind while working. The participants were also given a short debriefing interview at the end of each phase in which they participated (the designers were interviewed at the end of each phase and the OT was interviewed at the end of concept and detail design).

Concept Design

It was not known, at the beginning of concept design, how long the design team would need to work with the OT. The two hours specified in the initial design plan was a best guess as to how much would be needed. To determine the correct amount, it was decided to shorten the concept design phase to 4 hours but have the OT work with the design team during the entire time. If more time was needed, it would be allowed if necessary. This would allow the entire session to be reviewed after it was over to determine the necessary length of the session as well as the most appropriate time for input to be provided.

The designers and the OT were debriefed after the phase and a number of answers and potential issues were revealed. The main observations from the concept design were:

- 4 hours was a comfortable amount of time to perform the concept design.
- The design team also indicated that having input during the entire concept development process was useful
- The students expressed a desire for a product usage scenario to be part of the design brief. The original brief explained the design problem and what functionality the finished product must have, but did not describe the environment that it was intended for. In this case, the design team wanted to know if the product was intended to be used in an industrial environment (such as a factory) or in a home environment.
- The estimated time commitment for the study was provided to the pilot study designers before they agreed to participate as well as in the additional instruction materials provided when they arrived for the study. Despite this, one of the team members felt that the amount of time that they would have to spend working on the project was far beyond what they expected (even though the amount of this

member actually spent working on the project was much less than what was stated in the study materials).

- Although the designers spent the entire concept development phase with the OT, the OT indicated that the design team really did not ask very many questions. The only questions that were inquired about were related in some way to issues specifically stated in the design brief. The students did not naturally ask any other questions about dexterity limitations to learn about limitations and issues that might affect their design but were not necessarily mentioned in the design brief.

System Design

The study materials suggested that system design would require about two hours of work for each of the 7 days of the phase (14 hours of work from each team member) in order to produce a first working version of the design prototype. As with concept design, defining system design to be this length was a best guess. It was possible for this phase to take slightly more or slightly less time. Of course, if it took a significantly longer time than expected, this would have been an indication that a student design team would not be capable of producing a working prototype.

The main observations from the system design phase were:

- The outside schedules of the students showed itself as an issue during this phase. One of the students had a design studio review during the middle of this phase and did not spend any time working on the study during the first three days. The students had not been specifically instructed that it was ok for them to work separately. They thought that any work on the study had to be done together. They were informed that the intent was to allow them to divide the design work so that they did not always have to be working together.

- The design team members in the pilot did not work well together at all. One student (the junior) was very engaged and treated the study as if working for a client. The other student (the senior) was not very engaged and viewed the study as a secondary priority. This resulted in one student performing practically all of the work. The students also did not particularly like one another and which led to some friction and frustration between the two.
- The students' pattern of working appears to be that not much work was done at the beginning of the phase. The result was that they had to spend much more time working during the last days of the phase to complete the deliverable on time.
- The instructions given to the students described the type of input that they would receive during the course of the study. However, once system design started, the students began to ask if they could use items such as gloves and other tools to aid in their design. The students had to be told that this was not allowed, indicating that better instructions to the design teams are needed, particularly on issues related to what they are allowed to use to learn about dexterity limitations.
- It became clear that more information about the object of the study should be explained in the additional materials. The designers did not realize until about half way through the system design phase that their prototype would actually be given to users to perform the task after they were finished. This piece of information seemed to change their approach to the study somewhat. They became more focused knowing that other people would be examining and using their work after completion and that it was not intended to be just a simple study model that might be submitted for class work.

Detail Design

Like the previous phases, the initial length of time estimated for detail design was a best guess. Again, two hours of work per day over 3 days was suggested (for a total of 6 hours for each team member). Since this phase also included user input, the OT was made available to meet with the design team members at any time over the three days of detail design. For all of the pilot study, the students worked mainly in the shop at CATEA. The OT also worked at CATEA, so the students were instructed to simply come to the OT at any time during the day with questions requiring input. From the way that the designers utilized the OT during concept design, the team was instructed that they had to let the OT evaluate their prototype so that design problems could be identified. The team had to know that the professional input was not optional since the impact of that input is what the study intends to measure.

The main observations from detail design were:

- The students indicated that detail design felt rushed. However, without any other outside influences, it could be completed in three days, although they would likely spend more than 2 hours per day working.
- The design team indicated that \$60 for prototype materials was reasonable. The pilot team actually used less than this amount.
- Although the OT was available to the design team for the duration of detail design, the students requested input infrequently. The meetings that were requested were very short.
- The final debriefing revealed that the OT was hesitant to say much to the designers or offer unsolicited suggestions and information. This was not intended since an OT on a real world design project would most likely offer any information that would, in their opinion, help a design team find the best possible solution.

Conclusions and Changes to the Study

Based on the pilot run, a number of changes will need to be made to address problems that arose:

Changes to the Study Schedule

- The pilot showed that it is preferable to provide input for the entire concept design phase. Since the timeline for the design is short and the first phase is so important to help get the designers on the right track for the following phases, the direct input (user and OT) will work with the design teams during the entire concept design phase.
- The pilot design team lost the first few days of system design because they thought they had to work together all of the time. If they are informed that they are allowed to work separately, the time for this phase could be reduced to 5 days. The main goal of the system design phase is to ensure that the team has enough time to produce a rough prototype. The team will need some time to build on their own so that any technical issues that inevitably arise when a concept idea is converted to physical form can be worked out. The goal of the phase is to ensure that this first rough prototype of the concept is ready so that input can be provided on the implementation of the concept. This should be possible with teams sharing the workload.
- The reduction in the system design phase will be complimented by an extension of the detail design phase. It will be changed from 3 to 5 days in length. The main reason for this is to allow time for some design iteration of the prototype. This will give the design teams time to correct issues identified by input.

- Input will be provided to the design teams twice during detail design. The pilot showed that these sessions are not necessarily long but that they are still important. The OT and user input will be provided to the design teams for 1 hour on the first day of detail design and then again for 1 hour on the third day of detail design.

Design Brief Changes:

- The design brief will be updated with a scenario to describe that device is intended to be a commercial product that can be used in a typical office environment.

Changes to Instructions

- The instructions to the students will be modified in several ways.
 - The estimated time commitment will be placed more prominently. The estimated commitment will also be explained. For example, a student might truly realize what an estimated working time of approximately 24 hours really means because it is spread out over a long period. Examples will be provided (ie, a 24 hour commitment would be like working for 6 hours per day over two consecutive weekends) to help ensure that the designers have a clear understanding of the amount of time that will be involved (and so they can better decide before starting if it is something that they really want to do).
 - The study is spread out to allow enough time for design activities to be performed but also to allow some flexibility to work around individual scheduling conflicts. The designers will be strongly encouraged to work for short intervals each day.

- Each design team will be instructed more specifically on what types of input they will receive during the design process and what resources they are allowed or not allowed to use.
- All design teams will be provided with more information about the study up front. The end goal of the study was not explained to the pilot team (only the design task was outlined in detail). The things that the study is measuring will be described so that designers understand why they can or cannot get certain types of input (otherwise it might seem arbitrary). The designers also need to know that actual users with dexterity limitations will eventually be using and evaluating their prototypes for how well they function as well as how satisfied they are with it. This will allow teams understand the importance of building a prototype that is not flimsy and one that is well finished.
- Although a scenario for the use of the product will be described in the design brief, the additional instructions will also state that the most important thing to focus on during the design process is to implement the best solution possible based on the type of input they will receive. It will re-state that the prototypes will be evaluated for effectiveness and satisfaction, so the challenge to the team is to design a product that not only performs the task well for the users but is also one that they would be satisfied with using. Both of these aspects need to be explored through the input that is made available to the team.
- Teams that will receive input need to be instructed to actually use it (since this is the object of the study). This may seem obvious, but the pilot team used the OT more as an optional resource.

- Instructions need to be created to guide the OT as well as the users who will provide input to the design teams. They need to be encouraged to freely offer opinions on design ideas as well as offering unsolicited information about their challenges, day to day issues and how those are overcome.
- The design teams need some additional up front information about dexterity limitations. A fact sheet of basic information will be compiled to be given to each design team. Since none of the team members will have any previous experience with the issue, they will need a common base from which to begin their research. In particular, it will help the user input sessions as it will give the designers a broader initial base that they can use to ask questions, come up with ideas and imagine scenarios so that they can gather the input needed create a good initial concept.

Inclusion/Exclusion criteria

- The recruitment survey should determine if students hold jobs outside of school. In the pilot, this greatly reduced the availability of one of the design team members. Though some students would definitely be able to handle the schedule, an outside job will make full participation in the study much harder. So, if a student holds an outside job, they will be excluded from participation.

Other issues

- The largest school related scheduling issue for student designers is with design studio reviews. The studio schedule for juniors and seniors will be obtained so that the start dates of the various student design teams can be set so that they conflict (as little as possible) with studio reviews.
- The design skills of the two designers in the pilot were relatively close to one another. The junior that was used was an A level student and the senior was a B

level student (a little below the cutoff for the experimental study). Because their skills were similar the team aspect would not have provided much, if any, balancing effect. It was briefly discussed that it might be possible to use a single designer and take an extra measurement of the four input conditions (for a total of 12 products instead of 8). However, given the practical scheduling challenges, and the fact that product design is typically done in teams, there is more benefit to using 8 design teams of 2 two members rather than 12 design teams of 1 member.

APPENDIX K

PRODUCT EVALUATION PROCEDURES

The following script was followed for conducting each of the 20 product evaluation sessions. It included pre-session setup tasks and the script that was followed with each user to guide them through the dexterity tests, use of each product and survey completions.

Pre-Evaluation Tasks

- Make a copy of the informed consent form.
- Assign the user a participant ID and place this at the top of the consent form
- Make 9 copies of the evaluation form
- Make 9 copies of the product ranking survey form
- Put the participant ID number on the top of each page of the evaluation form
- Have 5 extra copies of the evaluation form ready in case they are needed (only put the participant ID on these if they are actually needed)
- Prepare the 9 boxes that will be taped closed by the user:
 - Each box should contain 1 ream of paper
 - Each box should be filled the rest of the way to the top with packing peanuts so that the flaps of the box do not cave in when closed and pressed but also so that the closed box flaps do not bulge out.
 - Prepare an extra 4 boxes to be used as practice boxes by the users
 - Have a utility knife available so that tape can be removed from practice boxes so the boxes can be re-used for practice during the evaluation.
- Make sure materials for the 9 hole peg test are ready
- Make one copy of the DASH survey with the participant ID written at the top of the pages

- Have the pinch/grip measurement devices ready
- Make one copy of the product evaluation data sheet with the participant ID written at the top
- Make one copy of the W9 form
- Make one copy of the Receipt of Compensation form
- Determine order that the products will be evaluated in. The order should be random and should be determined beforehand by pulling the names of the products out of a hat. The product names should be filled into the product evaluation data sheet in the order that they will be evaluated before beginning.
- Have a stopwatch available
- Prepare one standard tape dispenser for evaluation

Evaluation Tasks

- 1) Welcome user and have them fill out informed consent. Say something like:
 “Thank you for coming. Before we get started, I will need you to read and sign the official informed consent form. This language in this form is similar to the email invitation that you most likely received, but please read over it and let me know if you have any questions.”
- 2) Next, explain to the evaluator a little bit about the study:
 “The products you will be evaluating were designed by student design teams over the course of the last semester. During the design process, each team was given different kinds of input to help them learn about the design problem and come up with a solution. The design problem for this study was to design a product that will allow users with limited dexterity to successfully and independently tape closed a box. The ultimate goal of this study is to measure what effect, if any, the different kinds of input had on the final product. The aim is to discover ways to

improve the product design process so that ultimately, better products can be created. The product will be judged by measuring how effective it is at doing what it was designed to do as well as how satisfied users are with actually using the product. This data is being gathered by potential end users since these are typically the things that matter more to them than anyone else.”

3) Measuring Dexterity

- Say to the user:

“Before we begin to evaluate the products that were designed during the study, we will perform a few quick tests to measure your level of dexterity. Each of these tests is a standard or commonly used measure. They are being collected to provide an objective measurement of dexterity so that we can evaluate whether this has any effects on the data that we will collect during the evaluations.”

- DASH Survey

- Say to the user:

“The first measurement we will do is a self evaluation called the DASH survey. This stands for Disabilities of the Arm, Shoulder and Hand. It was developed by clinicians and researchers. Please read the instructions and let me know if you have any questions.”

- Give the DASH survey with the user’s participant ID on it to the user and allow them to fill it in.

- 9 Hold Peg test

- Say to the user:

“The next test is called the 9 hole peg test. It is a tool commonly used by occupational therapists to quickly assess finger dexterity. Let me explain how the test will work. In front of you is a board with 9 holes and beside it is a container with 9 pegs. The object is to place all 9 pegs into the holes. The pegs must be

placed into the holes starting from the top and filling in each row from left to right. Once all of the pegs are in the holes, you will then remove the pegs and place them back into the container. The pegs can be removed in any order, it is up to you. I will time how long it takes for you to place all of the pegs on the board and then return them to the container. I will tell you when to begin. If you like, you may practice placing the pegs 1 time only.”

- Pinch and Grip measurements
 - Say to the user:

“The final test is to measure your pinch and grip strength. We will take three measurements of grip and three measurements of pinch strength.”

4) Product Evaluation

Procedure for Each Product Evaluation

- The products should be arranged in the order that they will be evaluated in before the user arrives with boxes loaded and ready to go.
- The “Instructions to be said to the user” (below) should be read.
- The user **should** be encouraged to use the product on a test box before each evaluation. They don’t need to necessarily close the box completely during the test, but they need to have a good idea of how it works before they actually do the evaluation task.
- For each product:
 - Have the user get ready and tell them that you will tell them when to start
 - Start the timer when you say “Go”
 - Stop the timer when the user has successfully taped the top of the box flaps closed

- If the user was unable to finish the task, record “NF” for no finish as the time and ask the user why they were unable to perform the task and record their answer.

- Instructions to be said to the user:

“Now we will begin the product evaluations. For this, you will use each of the products that was designed during the study to tape closed a box. For taping the box, you will simply use the product to place a single strip of tape along the top flap of the box with each of the products. An identical box has been prepared and placed by each of the products for this purpose. We will do the products one at a time and I will give you instructions on how to use each before beginning the task for that product. You will then have a few minutes to practice with the product to get a feel for how it works. Once you are comfortable with how the product functions, you will tape a single box closed with the product. A single strip of tape will be used to close the top of each box. I will demonstrate this before we start. I will time and record how long closing each box takes. Even though I am timing, it is important to keep in mind that it is not a race. The most important thing for the evaluation is that you successfully close the box. So, do not try to work so fast that you are not able to close the box. If you have any questions you may ask me at any time. After you have completed the task with each product, you will fill out a short survey to measure your level of satisfaction with the product and how effective you felt that it was.”

- Control Product (this will always be first)

- Say to the user:

“The first product was not designed during the study. It is a common packing tape dispenser. We want to evaluate this first so that it is a reference that you can use to compare whether products designed during the study are better or worse.”

- Study Products

Provide each of the study products to the users in the order that was determined before the session to be evaluated.

- Have the user complete the product ranking survey.

Post Evaluation Tasks

- Score the DASH survey and record data
- Enter all of the evaluation survey and other data collected into the data collection spreadsheet

APPENDIX L

DESIGN STRUCTURE MATRIX PARTITIONING

This example is a sample DSM of the development of an alternating pressure wheelchair seat cushion. The development tasks and dependencies were mapped out in the matrix. Partitioning was performed on the matrix to reveal the best order for the development tasks to be performed in, based on their dependencies. This appendix will present a brief description of how the design structure matrix can be used to not only find the best ordering for design tasks but also be used to estimate the impact of design iteration and calculate the amount of time needed to complete all design tasks, including time needed for iteration.

DSM was first applied, not to design problems, but to management problems to help overcome shortcomings of standard project management techniques that were unable account for the iteration of tasks in a project plan. Iteration arises when one the input of a first task depends on the output of a second while at the same time the input of the second task depends on the output of the first. In other words, a task A depends on B and B also depends on A. One task cannot be performed accurately without knowing or assuming the results of the other. One example that he gave of this type of relationship is of a heat exchanger: the size of the exchanger depends on the coolant temperature but the coolant temperature depends on the size of the exchanger. These relationships arise frequently in many real world problems and become more complex as the number of tasks that depend on each other increase. DSM provided a way to analyze these iterative, interdependent tasks and suggest a linear, non-iterative order in which they can be most efficiently performed. Once in order, the tasks could be managed normally by any of the standard project management techniques. Analyzing a set of tasks using DSM not only helped to managing complex tasks, it also had the added benefit of providing an analytical way to view and study the structure of a problem (Steward 1981).

Christopher Alexander pioneered work analyzing how complex problems can be broken down into smaller pieces that can individually be solved more easily (Alexander 1964). A similar concept in design is called modularity (Carliss Y. Baldwin 2000). For any given problem, there are many ways to look at it. In other words, there is more than one way that it can be broken down. The modules generated by each approach to a problem may look quite different but each approach, though different, solves the same problem. DSM is not a tool that can be used to solve a design problem. The breakdown of a design problem and the approach that will be used to reach the solution must be mapped out. It can be used to view the modules but does not create them. Once the tasks and interdependencies are entered, DSM can be very useful in finding the best way to proceed with the defined tasks. Investigating the process of how design problems are actually solved and how the tasks are created is beyond the scope of this paper. It has been investigated by many others (for a collection of examples, see the book Analyzing Design Activity (Nigel Cross 1996) which is dedicated to the issue). It is mentioned here because, as we will discuss later, the way that a problem is broken down will directly affect the structure of a design solution and can have a direct effect on when users become involved in the design process.

A sample DSM of six tasks is shown in Figure L.1. The predecessors identified for each task are represented by 0's placed into the column corresponding to the task that it depends on. So, in this example: 'Task 1' depends on both 'Task 2' and 'Task 4'; 'Task 2' depends only on 'Task 3'; and so forth. The diagonal line of blackened squares does not represent any dependency. This is because any given task cannot depend on itself.

	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6
Task 1		0		0		
Task 2			0			
Task 3						
Task 4					0	
Task 5	0		0	0		0
Task 6			0			

Figure L.1 A sample DSM precedence matrix

The next step in analyzing a DSM is to re-order the tasks based on the dependencies. This is done by a process called partitioning. The main goal of partitioning is to attempt to arrange the rows so that all of the predecessors for each task lie below the diagonal. Since each predecessor basically represents an unknown value, if the tasks are arranged so that dependencies are all below the diagonal, then it would mean that the value the current task depends on would have been determined by the output of a previous task. This can be seen in the partitioned version of the sample DSM in Figure L.2. Re-ordering the tasks reveals that Task 3 should be performed first since Task 2 and Task 6 depend directly on its output. Simply doing it first eliminates the need to make guesses about its result. Tasks 2 and 6 can then be done without worrying that their results will be incompatible with Task 3.

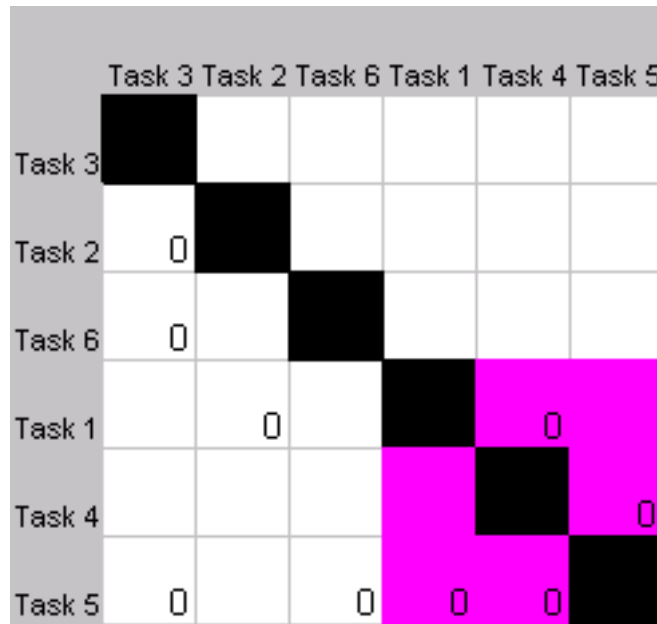


Figure L.2 A sample DSM after partitioning

A linear ordering is not always possible. This situation can be seen in the last three tasks in Figure 5. Each of these tasks depends directly on the output of one of the others. No matter what order these three tasks are performed in there will always be an unknown value because of a task that has not yet been performed. This is one of the ways that iteration can arise during design. In this case, a best guess must be made about what the output of the unperformed task might be. In Figure 5, Task 1 depends directly on Task 4. To complete Task 1, the output of Task 4 must be guessed. When Task 4 is performed, the actual output may be incompatible with the guess that was made to complete Task 1. If so, Task 1 must be performed again. This situation is more complicated because Task 4 depends on Task 5. When Task 5 is complete, it may cause Task 4 to be re-worked which could in turn cause Task 1 to again be re-worked. These interdependencies are what cause iteration to arise in a design. The set of tasks must be re-worked until the results of each one are compatible with the others.

Most project management techniques are not able to account for sets of tasks that must be repeated an unknown number of times. Most require that the design tasks are arranged in a linear, non iterative order. Steward introduced a technique called tearing that allows iterative tasks to be arranged in linear order with the least chance of having to be redone. The procedure for tearing is very similar to some of his other work on finding ways to more easily solve systems of linear equations. This involves partitioning a system of equations in matrix form and then analyzing it with a computer to identify key variables that can be removed from the system to make them easier to solve. This allows the system to be broken up into smaller, more easily solved systems. The small systems are later put back together to find the solution to the original problem (Steward 1965).

Instead of solving a system of equations, in DSM the technique allows us to find the best order for a group of tasks by making strategic guesses. The dependencies (variables) above the diagonal are assigned a value between 1 and 9. This value corresponds to how accurately the final output of a task can be estimated. If a very good guess can be made, it is given a 9. This could happen if the design team has past experience with similar tasks and has a clear idea of what must be done for the task to be successful. A less sure guess gets a lower value. The highest values are then removed one at a time and the DSM is re-partitioned. This process is continued until no tasks are left above the diagonal. This gives a best linear order for the tasks that requires the least amount of estimation. Once ordered, the tasks can be managed using a more common project management technique.

Ordering the tasks this way will help reduce the need to redo tasks, but it does not actually eliminate the need for iteration of the design tasks. This could be a problem since iteration tends to be a big source of added time in a project. Finding ways that it can be managed and reduced is important (Robert P. Smith 1997). Instead of making estimations, a technique that can account and measure the impact of iteration on a design project would be useful. Smith and Eppinger proposed two formal frameworks for doing

this. One is for the case of sequential iteration: where a set of related tasks are performed one task at a time. Individual tasks are repeated if errors are found and stopped when there are no further problems. The other is for parallel iteration: where all tasks are performed at the same time and repeated together until a solution is found. A real project will often involve a mix parallel and sequential design though it may favor one or the other based on outside factors. For example, a project might be performed largely in parallel if the tasks in the project are very closely related and the team working on them is geographically together and work very closely. Tasks may be performed in sequence if the tasks are not closely related and/or the design team is geographically distributed. We will use the sequential iteration model in a later example, so an overview of the method along with an example from Smith and Eppinger's paper will be presented here (Robert P. Smith 1997).

The initial steps in setting up the DSM are the same as we have already seen. The problem must be broken down into its component tasks, dependencies between these tasks must be identified and the DSM is partitioned as before. The next step is a little different; each dependency given a rework probability. This is the probability that a particular task will have to be repeated in relation to its dependant task. Each task is also assigned a duration, which is the time it would take to complete if it were done individually. This representation can be seen in the example in Figure L.3.

	A	B	C
A	4	.2	
B	.4	7	.5
C	.3	.1	6

Figure L.3 Sample DSM showing task times and rework probabilities

The diagonal elements have been replaced with the task times. So, task A would take 4 units of time and task B would take 7 units of time. The dependency marks on each row have been replaced by the likelihood that the output of the task will be incompatible with another task that depends on it and thus have to be repeated later. Tasks A and B are examples of this. If task A is done first, there is a probability of 0.2 that it will have to be repeated because the results of task B, when it is executed, are incompatible with the original results of task A. If task B is done first, then there is a 0.4 probability that task B will have to be repeated because its results will be incompatible with A.

A few assumptions about the design process are made at this point. It is assumed that the next task begins as soon as the preceding one is complete. In other words, things such as mis-communication between designers or any other issue that might cause a delay in performing the next task are not considered. Next, if a task is repeated, the amount of time it takes to perform does not change. Finally, the rework probabilities remain fixed for the entire project. It is possible that during a project the probability of performing rework on a particular task might change. It might go down if a designer is able to focus more on a problem and reduce probability of having to rework the task later. It might also increase if it is discovered that a problem is more complex than originally thought. The time needed to perform the task may vary as well for the same reasons. It is not possible to know exactly how either of these might change beforehand. The times and probabilities should be set by designers who are most familiar with the project so that the values are as close as possible. Variation of these will certainly occur in a project, but since they are as likely to increase as they are to decrease, the initial estimations can still serve as a useful guide.

With these assumptions in place, each of the iterative blocks can now be analyzed. The DSM has been partitioned at this point, but the best order in which to perform the tasks has not been determined. A method other than tearing must be used to

determine this since we want to calculate the effect iteration rather than remove it. One mathematically well understood way to do this is by representing the DSM as a reward Markov chain (Ross 1983). The optimal ordering can be found by defining a reward Markov chain for each possible ordering of the tasks, solving the system of equations for each unique ordering and choosing one that gives the best result.

One possible Reward Markov chain of the example DSM from Figure 6 is shown in Figure L.4. The chain itself is divided into stages. A new stage is entered whenever a task is attempted for the first time. It is possible for a task to be repeated, but once a stage is complete (ie a new task is performed for the first time), the stage itself cannot be repeated. Each node in the chain represents a task in an iterative process and each stage in the chain contains as many nodes as there are tasks that could have been undertaken in that stage. So, the number of nodes in each stage grows by one when each new stage is entered. Once the chain, showing the time for each task and the probabilities of moving from one to another, the total time for the ordering can be calculated.

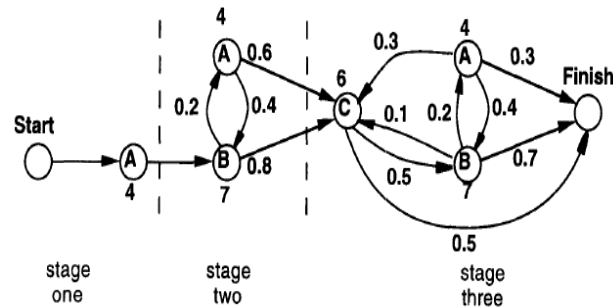


Figure L.4 Reward Markov chain of the sample DSM

To do this, one can observe that earlier stages are sub-components of later stages, ie stage two is completely contained within stage three. This can be taken advantage of to lessen the workload of calculating the time. Since no stage can be repeated, once defined, the time for each can be calculated independently and the results for each added to give the total. This feature greatly reduces the amount of work that would be required if using standard reward Markov chain analysis.

The analysis begins by starting from the last stage and working backward. So, the expected time remaining at each of the nodes in the third stage of our example in Figure 8 can be represented by:

$$r_A = 0.4r_B + 0.3r_C + 4,$$

$$r_B = 0.2r_A + 0.1r_C + 7,$$

$$r_C = 0.5r_B + 6$$

It should be noted here that the system of equations describing the reward Markov chain for the final stage can be read directly from the DSM by looking down each column in the matrix. This is helpful since it means that the reward Markov chain does not have to be drawn (as in Figure L.4) just to derive the equations for each stage. One other related note should be made here as well. The sum of the probabilities in any individual column in the task block in the DSM cannot be greater than 1. This is because the total probability of moving from one task to some other cannot exceed 100%. The equations above for stage 3 can be re-written as a matrix of equations:

$$\begin{bmatrix} 1 & -0.4 & -0.3 \\ -0.2 & 1 & -0.1 \\ 0 & -0.5 & 1 \end{bmatrix} \begin{bmatrix} r_A \\ r_B \\ r_C \end{bmatrix} = \begin{bmatrix} 4 \\ 7 \\ 6 \end{bmatrix}$$

The value of r_C above gives the expected time spent in node C during stage 3. This is calculated and found to be 11.21.

Next, the time expected to remain in node B in stage 2 is found. Since stage 2 is a subset of stage 3, the system of equations for stage 2 can be written by simply dropping the last row and column:

$$\begin{bmatrix} 1 & -0.4 \\ -0.2 & 1 \end{bmatrix} \begin{bmatrix} s_A \\ s_B \end{bmatrix} = \begin{bmatrix} 4 \\ 7 \end{bmatrix}$$

The time spent in node B during stage two is the value of s_B above. Solving for it gives the value of 8.48.

Stage one is a single state with no iteration so the total time for it is simply the task time of 4.

The time spent in each node that begins a new stage includes the probable time needed to re-work other tasks so that all results are compatible. The total for the entire system is thus the sum of these values: $11.21 + 8.48 + 4 = 23.69$.

A total of 6 unique orderings of the tasks in Figure 6 is possible, so to find the best order, the total time given by the other five must also be calculated. The above calculation would be repeated for each and the one with the lowest result would be picked. For very small systems, doing this is not difficult. But, as the number of tasks increases, this approach can quickly become impossibly time consuming. The chart below shows how quickly the number of possible combinations can grow as the number of tasks in the matrix increase:

Number of Tasks	Possible combinations
1	1
2	2
3	6
4	24
5	120
6	720
7	5040
8	40320
9	362880
10	3628800
11	39916800
12	479001600
13	6227020800
14	87178291200
15	1307674368000

As the number of tasks in the chain grows, calculating the expected time for every possible combination of tasks to find the best ordering becomes impractical. To solve this problem, Smith and Eppinger proposed a method for searching through the possible combinations to find a good solution. To do this the coupled tasks are set to some initial

order. The expected duration of this first ordering is calculated as described and the result is stored as the best value. Next, the first task (because analysis begins at the last stage, this is the same as the first row in the system of equations defined by the final stage of the reward Markov chain) is set to be a “mobile task”. The mobile task is moved down one position and the expected time of the new ordering is calculated. If the expected time is less than the best time found so far:

- The result is stored as the new best value
- The new ordering is saved as the best ordering
- The first row in the new ordering is set to be the new mobile task
- The new mobile task is moved and the calculation is repeated

If a new best is not found, the mobile task continues to move down one row at a time until it returns to its original position. If this happens, the second row is set to be the mobile task. It is moved until a new best is found (and the process starts over beginning from the first task again) or until the mobile task returns to where it began. Whenever a task returns to its starting point without finding a new best, the next task becomes the mobile task. This continues until each of the tasks has been the mobile task and been in every position without finding a new best value.

Smith and Eppinger tested this method with an 8 x 8 DSM whose best ordering was known. Fifty random initial orderings for this DSM were generated and calculated using this search method. In this test, the search always found a solution that was at least within 0.1% of the best possible ordering, and often found the best ordering. Examining every ordering in an 8x8 DSM would require calculating the result for 40,320 (8!) unique combinations. The search method is a significant improvement since it only has to examine approximately 8^2 orderings to achieve almost the same result. While it is not guaranteed to find the best ordering, it should find one that is very close in a much shorter

time. For the example case in the next section, a program was written to implement this method and was used to calculate durations.

A larger project may contain multiple blocks of iterative tasks that correlate to modules within a product. By ordering the tasks for the entire design project and then calculating the time needed for each of the modules, the overall time needed to complete design tasks with all rework time included can be calculated. The blocks of tasks that correspond to design modules show ideal points to integrate additional input into an evolving design. Input may come at the beginning (to help guide the work about to be performed) or end of a module (to critique work that has been completed). User input during the middle of a module may be less valuable since they generally are not as good at imagining and providing accurate input as they are if something has been created. Input is potentially most effective if it can be provided at the moment it is needed during design. If the potential effect size of different types of input is known, the most appropriate input can be provided at the right moment. If the input is more effective at helping designers learn about and devise better solutions, it has the potential to further reduce design iterations that are needed.

APPENDIX M

INSTRUCTIONS GIVEN TO USERS FOR INTERACTION WITH DESIGN TEAMS

The following instructions were given to the user group who provided input to the two design teams that received their input. The goal of these instructions was to allow the users to give their input as freely as possible but not in a way that would cause both of the user input teams to end up designing essentially the same product. The users were instructed to allow the designers to lead with generating ideas and to provide them with any input required to help them come up with an acceptable solution, whether that meant rejecting an idea completely or working with any of the ideas that came up during sessions with the design teams.

This document is meant to guide you in how you should interact with the design teams during the study. These guidelines are very important to the success of the study, so it is important to read and follow them carefully. The goal for the designers is to learn as much from you as possible about dexterity limitations and day to day challenges. The designers will not only be learning from you, but working with you to create a product that will allow a user with limited dexterity to pack and tape closed a box independently and accurately without assistance from others.

To help the designers do this, there are a few things we would like you to keep in mind during the input sessions:

- The designers' main objective is to create a product that will do two things:
 - It should be effective, in other words, the device being designed should be something that you think would be a good solution to the problem. The finished product should allow you to perform the task independently and efficiently.
 - It should be satisfying. For satisfaction, the design that is being created should be easy to use, comfortable to use, safe to use and it should be socially acceptable. In short, it should be a product that you would feel comfortable with and like using.
- You will be the only source of input that the designers have during the design process. The designers will not be familiar with issues or problems related to dexterity limitations so it is important to give them all of your opinions, thoughts and ideas for potential solutions. Since the design team will have no other chance to learn about dexterity limitations, if they do not learn about potential issues or preferences from you, then there will be no other way for them to find out about it. You will be the expert consultants to the design team.
- There is one minor restriction on your input that you should keep in mind while working with the design team. The designers have been told that they should come up with many design ideas, seek your opinion on them and then work with you to refine the ideas to find a good design solution. You should feel free at any time to describe and explain problems or issues. However, you should allow the design team to come up with possible ideas first. Once the design team has presented an idea, you may offer any opinion and suggestion about it that you wish. If you think that it will not work, let the designers know this and explain why you think the idea would not work. If you think the idea might be modified in some way that would be good, you should explain how you would modify the idea in a way that you think would work.

The reason for this restriction is that you will be providing input to two different design teams. For the study, we want to be sure that the basic input that the designers get is consistent (that is why there is not a different group of users giving input to the second team). We want the designers to have the opportunity to each get the same input, but we don't necessarily want the two teams to end up designing the same product.

These are all of the guidelines. To put it in a summary form, you should provide any and all information that you can to the designers that will help them create a design that you think a user with a dexterity limitation would find to be effective and satisfactory. The only restriction is that you should not actually offer new potential design solutions (although if you feel that a specific idea could be modified, you **should** suggest specific changes). Don't be afraid to constructively criticize any idea (after all, you are there to try to lead the design team in the right direction to create the best product that they can).

APPENDIX N

INSTRUCTIONS GIVEN TO OT FOR INTERACTION WITH DESIGN TEAMS

The following instructions were given to the occupational therapist who provided input to the two design teams that received OT input. The goal of these instructions were essentially the same as those given to the end users who were providing input: to allow the OT to give input as freely as possible but not in a way that would cause both of the teams to end up designing essentially the same product. The OT was instructed to allow the designers to lead with generating ideas and to provide them with any input required to help them come up with an acceptable solution, whether that meant rejecting an idea completely or working with any of the ideas that came up during sessions with the design teams.

This document is meant to guide you in how you should interact with the design teams during the study. The goal for the designers is to learn as much from you as possible about dexterity and how to solve the design problem. With few exceptions, you are free to (and should) provide any information that you can. This is important, because you will be the only source of information the designers have for the study.

- The designers have been instructed to ask questions to try to learn about the different problems that people with dexterity limitations face as well as about their abilities. However, since the designers will be inexperienced with the subject matter the designers may now know to ask about topics that may be important. So it is important, especially during the concept design session that

you offer information and prompt the design team to think about different topics that are important to consider for their design.

- The designers have also been instructed to consider you part of the design team while you are providing input. They have been told that since you are not a designer, then they should come up with many design ideas, seek your opinion on them and then work with you to refine the ideas to find a good design solution. During this process is the one restriction. You should bring up issues that the design team should think about (even if not asked directly), but you **should not** offer any specific solutions. The designers should come up with possible ideas first. You may offer any opinion and suggestion on a design idea that the design team brings up (including specific ways that an idea might be modified), but you should bring up solution ideas first.
- You should ensure that the designers are not just considering issues related to functionality. As much as possible, the design team should be made aware of issues related to how satisfying the finished product will be to use (ie, in your opinion, what would users **like**). The designers have been instructed to consider these issues, but you should ensure that these considerations are not overlooked.

That is pretty much it. You should provide any and all information that you can to the designers that will help them create an effective and satisfactory design. The only restriction is that you should not actually offer new potential design solution (suggestions for modifications to an idea are fine).

APPENDIX O

EVALUATOR RECRUITMENT FLIER

This appendix contains the flier and screening survey used during recruitment of the user evaluators.

Greetings,

The Center for Assistive Technology and Environmental Access (CATEA) at Georgia Tech. is looking for volunteers to participate in the evaluation of a number of product prototypes. The prototypes were produced as part of a study investigating the effect of input during the process of designing an Assistive Technology (AT) product. In this study, eight design teams created a product that is intended to allow users with dexterity limitations to independently pack and secure boxes (such as for mailing or storing items). Potential evaluators should meet the following criteria:

- aged 18 years or older
- have a limitation in dexterity
- are in the Atlanta area to take part in the evaluations
- do not have a sensory limitation (ie hearing or vision)

Procedures:

- Participants will each complete a short evaluation of dexterity. The evaluation will include completing a survey and performing pinch and grip tests.

- Participants will evaluate a total of 8 designs. The evaluation will involve loading and taping closed a box using each of the designs. An evaluation survey will be completed after performing the task with each of the designs.

The evaluations will take place at CATEA on the campus of Georgia Tech. Evaluation sessions will be conducted during the month of May and each is expected to last for **approximately three (3) hours**

Compensation to You:

Each participant will receive **\$60** in compensation for the evaluation of all 8 products. If a participant must withdraw before completing all 8 evaluations, compensation will be calculated by dividing \$60 by the number of device evaluations completed.

How to Volunteer:

If you are interested in volunteering, please fill out the survey at the bottom of this email and send the completed survey via email to Young Mi Choi at:
removed@mail.gatech.edu

If you are selected to participate, you will be contacted by study staff to organize a date and time for you to perform the evaluations at CATEA. Evaluations will take place during the last half of May and during June 2009. We will provide directions and parking information when a time has been coordinated with you. Each participant will be responsible for their own transportation to and from CATEA.

Risks/Discomforts:

The following risks/discomforts may occur as a result of your participation in this study:

- There is minimal risk involved with participation in this study. Risks involved are no greater than the risks normally associated with loading and taping closed a box.

In Case of Injury/Harm:

Neither the Principal Investigator nor Georgia Institute of Technology has made provision for payment of costs associated with any injury resulting from participation in this study.

Costs to You:

There are no costs to you for participation in this study.

Benefits:

You are not likely to benefit directly in any way from participation in the study. Indirect benefits include the opportunity to participate in research and the opportunity to help improve the design of AT products and services.

Confidentiality:

All information collected by this study will be kept confidential. Each participant will be assigned a unique ID number for the study. This ID number will be used in the collection of all data and materials during the study. The only link between your name and study ID will be stored with the consent forms in a locked cabinet at CATEA and will only be accessible by study staff for this project. Your name and any other fact that might point to you will not appear in any publication.

To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB (Institutional Review Board) may review the study's records. The Office of Human Research Protections may also look at the records. Again, your privacy will be protected to the extent allowed by law.

Subject Rights:

- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of the signed consent form to keep.
- You do not waive any of your legal rights by consenting to participate.

Questions about the Study or Your Rights as a Research Subject:

If you have any questions about the study or your participation, you may contact Young Mi Choi at by sending mail to removed@mail.gatech.edu or by phone at xxx-xxx-xxxx. If you have any questions about your rights as a research volunteer, call Ms. Melanie Clark, Georgia Institute of Technology at xxx-xxx-xxxx.

Thanks for your consideration,

Young Mi Choi

Ph. D. Candidate

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Screening Survey

(please return answers to Young Mi Choi at removed@mail.gatech.edu)

1) What year were you born? _____

2) What is your gender?

_____ Male

_____ Female

3) How long have you had limited dexterity?

4) Please indicate the types of dexterity related limitations that you experience (check all that apply)

____ Difficulty grasping

____ Difficulty squeezing

____ Difficulty holding

____ Difficulty with fine finger manipulation

5) Do you:

____ Mostly use both hands?

____ Mostly use your right hand but have limited use of your left hand?

____ Mostly use your left hand but have limited use of your right hand?

____ Have limited use of both hands?

6) If you have any other types of limitations (such as limited mobility), please briefly list them.

7) What is a phone number at which you may be reached?

APPENDIX P

DETERMINING BOX SIZE AND WEIGHT

This appendix contains the steps that were followed to test various boxes to determine the size of box and weight of the contents that would be used during the evaluation of the products that were designed.

The goal of the product evaluations was for end users to use the fabricated products to actually perform a task. This needed to be done since it is really the only way to show if it is effective or not. But actually using the product is also the only good way for a user to get an idea of how satisfying it is to use. It would be hard for a user to provide a rating of the satisfaction level of using a product without actually doing it. A question arose of what type size of box to use and how much stuff should be in it.

The design brief specified that the device should work over a wide range of box sizes. Since measuring effectiveness and satisfaction required the user to actually perform the task, it was important to make sure that all of the products could be operated with the size and weight of box that was chosen. A single box size with a standard weight would be used for the evaluations (otherwise it could confound the evaluation data). A series of tests detailed below was run using some of the first completed products to determine the size and weight of box that would be used in the study. The products were individually tested with large, medium and small boxes each with heavy, medium and light loads in them. We wanted to make sure that the product could successfully be used but also that issues such as box slippage were still factors. The final decision was to use a medium sized box with a medium load.

- 1) Allow about 5 minutes to play with the product to get a feeling for how it works and how to use it. We will allow the users time with each product during the real evaluations also (we will also have usage instructions for each then also) We want to get an idea of how long it takes working with the product to get a good feel for how it works so that the evaluators are not learning about how it operates while actually doing the evaluations.

* Ask Tester how long she feels like she needs to feel comfortable with how the product operates because we want to get a rough idea of how long we should allow the users to play with it before they begin their evaluation.

The test portion

Medium Sized Box, Medium Load

- 2) We want to take note of approximately how long it takes to complete steps 3-11 so record the time on the clock when step 3 starts.
- 3) First we will test one medium sized box. For this test, we will put in one ream of paper and one bag of packing peanuts.
- 4) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 5) Place the items to be loaded on a table in front of the evaluator.
- 6) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 7) Now have the user prepare to close the box.
- 8) Instruct the user to secure the box only along the top center line of the box.
- 9) Tell the evaluator “GO” to start using the product to close the box.

- 10) Stop the timer when the top of the box has been closed along the center and record the time.
- 11) Have the evaluator complete the evaluation survey for the product.
- 12) Record the time on the clock when step 11 is complete.

Next we want to test a small box with a light load to see if the interaction and evaluation is any different:

Small Sized Box, Light Load

- 13) We want to take note of approximately how long it takes to complete steps 13-23 so record the time on the clock when step 3 starts.
- 14) This test will be of a small sized box. For this test, we will put in a small journal or magazine and two bags of packing peanuts.
- 15) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 16) Place the items to be loaded on a table in front of the evaluator.
- 17) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 18) Now have the user prepare to close the box.
- 19) Instruct the user to secure the box only along the top center line of the box.
- 20) Tell the evaluator “GO” to start using the product to close the box.
- 21) Stop the timer when the top of the box has been closed along the center and record the time.
- 22) Have the evaluator complete the evaluation survey for the product.
- 23) Record the time on the clock when step 22 is complete.

Next we want to test a small box with a heavy load to see if the interaction and evaluation is any different:

Small Sized Box, Heavy Load

- 24) We want to take note of approximately how long it takes to complete steps 25-33 so record the time on the clock when step 3 starts.
- 25) This test will be of a small sized box. For this test, we will put in 3 reams of paper.
- 26) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 27) Place the items to be loaded on a table in front of the evaluator.
- 28) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 29) Now have the user prepare to close the box.
- 30) Instruct the user to secure the box only along the top center line of the box.
- 31) Tell the evaluator “GO” to start using the product to close the box.
- 32) Stop the timer when the top of the box has been closed along the center and record the time.
- 33) Have the evaluator complete the evaluation survey for the product.
- 34) Record the time on the clock when step 33 is complete.

Next we want to test a large box with a heavy load to see if the interaction and evaluation is any different:

Large Sized Box, Heavy Load

- 35) We want to take note of approximately how long it takes to complete steps 36-44 so record the time on the clock when step 3 starts.
- 36) This test will be of a large sized box. For this test, we will put in 3 reams of paper.
- 37) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 38) Place the items to be loaded on a table in front of the evaluator.
- 39) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 40) Now have the user prepare to close the box.
- 41) Instruct the user to secure the box only along the top center line of the box.
- 42) Tell the evaluator “GO” to start using the product to close the box.
- 43) Stop the timer when the top of the box has been closed along the center and record the time.
- 44) Have the evaluator complete the evaluation survey for the product.
- 45) Record the time on the clock when step 44 is complete.

Next we want to test a large box with a light load to see if the interaction and evaluation is any different:

Large Sized Box, Light Load

- 46) We want to take note of approximately how long it takes to complete steps 47-55 so record the time on the clock when step 3 starts.

- 47) This test will be of a large sized box. For this test, we will put in a small journal or magazine and two bags of packing peanuts.
- 48) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 49) Place the items to be loaded on a table in front of the evaluator.
- 50) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 51) Now have the user prepare to close the box.
- 52) Instruct the user to secure the box only along the top center line of the box.
- 53) Tell the evaluator “GO” to start using the product to close the box.
- 54) Stop the timer when the top of the box has been closed along the center and record the time.
- 55) Have the evaluator complete the evaluation survey for the product.
- 56) Record the time on the clock when step 55 is complete.

Next we want to test a large box with a medium load to see if the interaction and evaluation is any different:

Large Sized Box, Medium Load

- 57) We want to take note of approximately how long it takes to complete steps 58-66 so record the time on the clock when step 3 starts.
- 58) This test will be of a large sized box. For this test, we will put in one ream of paper and one bag of packing peanuts.
- 59) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 60) Place the items to be loaded on a table in front of the evaluator.

- 61) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 62) Now have the user prepare to close the box.
- 63) Instruct the user to secure the box only along the top center line of the box.
- 64) Tell the evaluator “GO” to start using the product to close the box.
- 65) Stop the timer when the top of the box has been closed along the center and record the time.
- 66) Have the evaluator complete the evaluation survey for the product.
- 67) Record the time on the clock when step 66 is complete.

Next we want to test a small box with a medium load to see if the interaction and evaluation is any different:

Small Sized Box, Medium Load

- 68) We want to take note of approximately how long it takes to complete steps 69-77 so record the time on the clock when step 3 starts.
- 69) This test will be of a small sized box. For this test, we will put in one ream of paper and one bag of packing peanuts.
- 70) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 71) Place the items to be loaded on a table in front of the evaluator.
- 72) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 73) Now have the user prepare to close the box.
- 74) Instruct the user to secure the box only along the top center line of the box.
- 75) Tell the evaluator “GO” to start using the product to close the box.

- 76) Stop the timer when the top of the box has been closed along the center and record the time.
- 77) Have the evaluator complete the evaluation survey for the product.
- 78) Record the time on the clock when step 77 is complete.

Next we want to test a medium box with a light load to see if the interaction and evaluation is any different:

Medium Sized Box, Light Load

- 79) We want to take note of approximately how long it takes to complete steps 80-88 so record the time on the clock when step 3 starts.
- 80) This test will be of a medium sized box. For this test, we will put in a small journal or magazine and two bags of packing peanuts.
- 81) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 82) Place the items to be loaded on a table in front of the evaluator.
- 83) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 84) Now have the user prepare to close the box.
- 85) Instruct the user to secure the box only along the top center line of the box.
- 86) Tell the evaluator “GO” to start using the product to close the box.
- 87) Stop the timer when the top of the box has been closed along the center and record the time.
- 88) Have the evaluator complete the evaluation survey for the product.
- 89) Record the time on the clock when step 88 is complete.

Next we want to test a medium box with a heavy load to see if the interaction and evaluation is any different:

Medium Sized Box, Heavy Load

- 90) We want to take note of approximately how long it takes to complete steps 91-99 so record the time on the clock when step 3 starts.
- 91) This test will be of a medium sized box. . For this test, we will put in 3 reams of paper.
- 92) We will take two time measurements. The first will be for how long it takes to load the items into the box. The second will be for closing the box.
- 93) Place the items to be loaded on a table in front of the evaluator.
- 94) Tell the evaluator “GO” to start loading the box. When all of the items are in inside the box, stop the timer and record the time.
- 95) Now have the user prepare to close the box.
- 96) Instruct the user to secure the box only along the top center line of the box.
- 97) Tell the evaluator “GO” to start using the product to close the box.
- 98) Stop the timer when the top of the box has been closed along the center and record the time.
- 99) Have the evaluator complete the evaluation survey for the product.
- 100) Record the time on the clock when step 99 is complete.

* Ask Tester if she has any feedback about the evaluation survey. Should other questions be included? Are the questions clear? Will the evaluators be able to give an answer to each of the survey questions based on their actual experience with using the product based on the evaluation procedures?

Box sizes:

Small 8-11 inches

Medium 12-16 inches

Large 20-24 inches

Loads:

Light Load = 1 magazine/journal and 2 bags of packing peanuts

Medium Load = 1 ream of paper and 2 bags of packing peanuts

Heavy Load = 3 reams of paper

Other items needed:

Stopwatch (for measuring times)

2 bags of packing peanuts (in individual bags)

One light journal or magazine

3 reams of paper

APPENDIX Q

PILOT EVALUATION INTERVIEW QUESTIONS

A single user participated in a pilot evaluation. The purpose of the evaluation was to test all of procedures. The procedures included things such as explaining and demonstrating how the devices were operated. It was important to ensure that these instructions were understandable. It also provided a chance to identify and fix any outstanding fabrication related issues before beginning the study. The pilot was also used to verify that the evaluation session could be performed within the 3 hours that was planned. The user evaluated each of the completed products and did all of the steps that were planned to actually gather the evaluation data. No major changes to the evaluation procedures needed to be made after the pilot. The questions below were asked to the user after completing the test evaluation.

- 1) What do feel about the overall length of the evaluation session? Is it too long or too short?
- 2) Were there any parts of the evaluation process that were too difficult?
- 3) What changes to the procedures would you make that could allow the process to be easier or more efficient for you overall?
- 4) Did you feel that there were any parts of the evaluation process that were unnecessary or confusing? Explain why?
- 5) Would you have preferred to do all of the evaluations over two separate sessions rather than in one single session?
- 6) Do you think that other user might have difficulty evaluating all of the products?

- 7) Did the workmanship of any of the products cause you to evaluate them higher or lower based on how they were made (in other words did you give lower scores in cases where the product just didn't function as well as it might have if it was better built)?

APPENDIX R

RE-WORDED EVALUATION SURVEY FOR EVALUATING CRONBACH'S ALPHA

This appendix contains evaluation survey that was used for calculating Cronbach's alpha coefficient before beginning the evaluation phase of the study. The survey was re-worded to ask the same survey questions but in a different way. Both versions of the survey were completed for each product during the pilot evaluation. Three additional volunteers also evaluated the completed products and completed both evaluation surveys. A high alpha score on the re-worded and non-reworded survey indicated that the questions very likely measure the same underlying constructs and were consistent enough to be used.

Participant ID:_____

Product Name:_____

Instructions: Please mark your opinion to each of the following statements.

** The column headings have been changed so that the table will fit between the margins.

On the survey used for testing the abbreviations in the headings were spelled out as:

SD = Strongly Disagree

SWD = Somewhat Disagree

NAG = Neither Agree nor Disagree

SWA = Somewhat Agree

SA = Strongly Agree

	SD	SWD	NAG	SWA	SA
1. It was easy to finish the task using the device.	1	2	3	4	5
2. The device helped to keep the box from moving around so that it could be closed.	1	2	3	4	5
3. It was clear how the device is supposed to be used.	1	2	3	4	5
4. Using the device did not cause me any pain or discomfort.	1	2	3	4	5
5. Operating the device was not difficult.	1	2	3	4	5
6. I did not feel like I would be injured when using the device.	1	2	3	4	5
7. I like the way the device looks.	1	2	3	4	5
8. Using this device would not cause people to take extra notice of my disability.	1	2	3	4	5
9. I think the product could have been built a little differently, but I think the concept of the product is good for the task.	1	2	3	4	5
10. I can close the box more easily with this device than with a 'standard' tape dispenser.	1	2	3	4	5
11. The way that this product actually performed in closing the box was better than other products (not from this study) that I have used before.	1	2	3	4	5
12. If I could get this device in a store I would buy one to use.	1	2	3	4	5

13. I think this product (pick one):

- ☐ Shouldn't be changed at all
- ☐ Could be changed some, but it is mostly ok
- ☐ Some things are good, some things are bad, it is about even
- ☐ Only some things were ok but mostly I didn't like it
- ☐ I dislike everything about this product

APPENDIX S

MODERATOR SCRIPT FOR THE PRODUCT EVALUATIONS

Moderator Instructions

Pre-Evaluation Tasks

- Make a copy of the informed consent form.
- Make copy of the media release form.
- Assign the user a participant ID and place this at the top of the consent form
- Make 9 copies of the evaluation form
- Make 2 copies of the product ranking survey form
- Put the participant ID number on the top of each page of the evaluation form
- Have 5 extra copies of the evaluation form ready in case they are needed (only put the participant ID on these if they are actually needed)
- Prepare the 9 boxes that will be taped closed by the user:
 - Each box should contain 1 ream of paper
 - Each box should be filled the rest of the way to the top with packing peanuts so that the flaps of the box do not cave in when closed and pressed but also so that the closed box flaps do not bulge out.
 - Prepare and extra 4 boxes to be used as practice boxes by the users
 - Have a utility knife available so that tape can be removed from practice boxes so the boxes can be re-used for practice during the evaluation.
- Make sure materials for the 9 hole peg test are ready
- Have the pinch/grip measurement devices ready

- Make one copy of the product evaluation data sheet with the participant ID written at the top
- Make one copy of the W9 form
- Make one copy of the Receipt of Compensation form
- Determine order that the products will be evaluated in. The order should be random and should be determined beforehand by pulling the names of the products out of a hat. The product names should be filled into the product evaluation data sheet in the order that they will be evaluated before beginning.
- Have a stopwatch available
- Prepare one standard tape dispenser for evaluation

Evaluation Tasks

5) Welcome user and have them fill out informed consent. Say:

“Thank you for coming. Before we get started, I will need you to read and sign the official informed consent form. This language in this form is similar to the email invitation that you most likely received, but please read over it and let me know if you have any questions. While you are using the products, I may ask if I can take a picture of how you use it. I have a media release form that you can sign if you don’t mind me using the picture in my dissertation. Otherwise, the pictures will be used simply as study data and never published.”

6) Next, explain to the evaluator a little bit about the study:

“The products you will be evaluating were designed by student design teams over the course of the last semester. During the design process, each team was given different kinds of input to help them learn about the design problem and come up with a solution. The design problem for this study was to design a product that will allow users with limited dexterity to successfully and independently tape closed a box. The ultimate goal

of this study is to measure what effect, if any, the different kinds of input had on the final product. The aim is to discover ways to improve the product design process so that ultimately, better products can be created. The product will be judged by measuring how effective it is at doing what it was designed to do as well as how satisfied users are with actually using the product. This data is being gathered by potential end users since these are typically the things that matter more to them than anyone else.

The allotted 3 hours to evaluate all 8 products is tight. I will try to move quickly from one task to the next. However, do not feel hurried since it is not a race and let me know at any time if you would like a break.

One other note. It is very important that you do not talk with other people that may be in this study about your experience with the products. This is not about secrecy, but for the data to be valid your opinion of the products needs to be completely independent and not influenced by anyone else. So, if you happen to know someone who is in this study by has not performed the evaluation, please do not discuss any details of the study with them so that when they arrive they will have no previous expectations of any kind.”

7) Measuring Dexterity

- Say to the user:

“Before we begin to evaluate the products that were designed during the study, we will perform a few quick tests to measure your level of dexterity. Each of these tests is a standard or commonly used measure. They are being collected to provide an objective measurement of dexterity so that we can evaluate whether this has any effects on the data that we will collect during the evaluations.”

- 9 Hold Peg test
 - Say to the user:

“The next test is called the 9 hole peg test. It is a tool commonly used by occupational therapists to quickly assess finger dexterity. Let me explain how the test will work. In front of you is a board with 9 holes and beside it is a container with 9 pegs. The object is remove the pegs from the container one at a time and place them into the holes on the board. The pegs must be placed into the holes starting from the top and filling in each row from left to right. When you have placed the last peg in the hole, remove your hand and say done. Next you will remove the pegs with your hand and place them back into the container. You may not just dump the pegs out but they can be removed in any order, it is up to you. I will time how long it takes for you to place all of the pegs on the board and then return them to the container. I will tell you when to begin placing the pegs and also when to begin removing them. If you like, you may practice placing the pegs 1 time only. We will perform the test once using your left hand and then once using your right hand.”

- Pinch and Grip measurements

Grip measurement – arm position at 90 degrees, like sitting in a chair with arms.

- Say to the user:

“The final test is to measure your pinch and grip strength. We will take three measurements of grip and three measurements of pinch strength with your right hand and also with your left hand.”

8) Product Evaluation

Procedure for Each Product Evaluation

- The products should be arranged in the order that they will be evaluated in before the user arrives with boxes loaded and ready to go.
- The “Instructions to be said to the user” (below) should be read.

- The user **should** be encouraged to use the product on a test box before each evaluation. They don't need to necessarily close the box completely during the test, but they need to have a good idea of how it works before they actually do the evaluation task.
- For each product:
 - Have the user get ready and tell them that you will tell them when to start
 - Start the timer when you say "Go"
 - Stop the timer when the user has successfully taped the top of the box flaps closed
 - If the user was unable to finish the task, record "NF" for no finish as the time and ask the user why they were unable to perform the task and record their answer.
- Instructions to be said to the user:

"Now we will begin the product evaluations. Each of the products was designed with a small office setting in mind. For the evaluation, you will use each of the products to tape closed a box. For taping the box, you will simply use the product to place a single strip of tape along the top flap of the box with each of the products. An identical box has been prepared and placed by each of the products for this purpose. We will do the products one at a time and I will give you instructions on how to use them and demonstrate its operation before beginning the task for that product.

You will then have a few minutes to practice with the product to get a feel for how it works. You can use the product as demonstrated but you may also choose to operate it differently if some other way works better for you. The practice time will give you a chance to become comfortable with how the product functions and how you can operate

it successfully. When you are ready you will tape a box closed with the product. A single line of tape will be used to close the top of each box. I will time and record how long closing each box takes. Even though I am timing, it is important to keep in mind that it is not a race. The most important thing for the evaluation is that you successfully close the box. So, do not try to work so fast that you are not able to close the box. If you have any questions you may ask me at any time. You can re-start the task if you wish (and I will restart the timer) or you can also give up if you think you will not be able to complete the task after trying the product.

After you have finished the task with each product, you will fill out a short survey to measure your level of satisfaction with the product and how effective you felt that it was. If the product is made up of more than one item, please consider all of the items when you are filling in the survey. The focus of this study is on getting your opinion of the products and is NOT concerned with issues such as manufacturing, marketing or other business related concerns. When filling out the surveys, focus on how well the product works for you and your personal opinion of it.”

- Control Product (this will always be first)
 - Say to the user:

“The first product was not designed during the study. It is a common packing tape dispenser. We want to evaluate this first so that it is a reference that you can use to compare whether products designed during the study are better or worse.”

- Study Products

Provide each of the study products to the users in the order that was determined before the session to be evaluated. Have them fill out the product evaluation survey and ask the

follow up interview questions. After all products have been evaluated, users should complete the ranking survey.

Say to the user:

“The instructions that I will read to you for each of the products are the way that the designers imagined that the product would be used. As I mentioned before, you can use the product in the way described or in some other way that works for you. During the practice time I will work with you to find an alternative way to use the product, if necessary, if you are not able to use it as described.”

Product Instructions:

Tape Puller Product:

To operate this product:

- 1) Slide either your left or right hand into the hand hold.
- 2) Push the front side of the device onto the box to begin applying the tape.
- 3) Lift up and then pull the dispenser across the top of the box
- 4) On the opposite side of the box, push down to apply pressure between the tape and the cutting blade to cut the tape.
- 5) Flatten out the tape so that it is firmly attached to the box.

Conveyor Product:

This product works by pulling the box along a conveyor belt and applies and cuts the tape automatically using a pivoting tape dispenser that is attached to an overhanging bar.

To operate this product:

- 1) Place the box on the conveyor belt.
- 2) Adjust the conveyor belt side bumpers to fit against the side of the box.
- 3) Adjust the height of the overhanging bar to match the height of the box.
This will keep flaps of the box held down while applying the tape.
- 4) Turn on the belt drive to pull the box through the device which will apply the tape.
- 5) Turn off the belt drive when the box has passed through the device.
- 6) Pat down the tape so that it is firmly attached to the box.

Powered Poll Product:

This is a powered product intended to help remove much of the manual work of closing a box. It is made up of a shelf that travels up and down a pole. The shelf can be adjusted to the height of a box that needs to be closed. The shelf contains a telescoping tape dispenser and a pair of arms that hold down the flaps of the box. The arms can be extended and retracted. The shelf can also be rotated left or right to align the arms and the tape with the box.

To operate the product:

- 1) Buttons on the base of the product control the taping shelf. The operation of the buttons, from left to right are:
 - Move the shelf up
 - Move the shelf down
 - Rotate the shelf clockwise
 - Rotate the shelf counter-clockwise

- Pull the powered arms in
 - Push the powered arms out
- 2) Adjust the height of the shelf so that it is slightly higher than the top of the box to be taped.
 - 3) Adjust the powered arms in or out so that they will come down on the box flaps when the shelf is lowered.
 - 4) Attach the tape to the side of the box closest to the pole.
 - 5) Lower the shelf until the box flaps are closed.
 - 6) Pull the telescoping tape dispenser past the far side of the box.
 - 7) Press the tape down so that it seals the box.
 - 8) Rotate the tape dispenser so that the tape is cut.
 - 9) Raise the shelf up from the top of the box.
 - 10) Push the telescoping tape dispenser back in and retract the powered arms.

Wall Mounted Product:

This product is designed so that it is possible to be used with one hand. To operate this product:

- 1) Open the stopper and put the box up against the board
- 2) Slide the vertical bar close to the box
- 3) Lift up the arm and set it on the box
- 4) Adjust the tape to be in the center of the box
- 5) Pull the tape flap onto the side of the box and then pull the handle to the left across the top of the box.
- 6) Pull the tape past the edge of the box and then allow it to come downward; this will cut the tape.

Cabinet Mounted Product

To operate this product:

- 1) Unlatch the arm and swing down the tape dispenser by holding the strap
- 2) Pull the dispenser down so that it is at the correct height to apply tape to the top of the box.
- 3) Align the box with the tape
- 4) Affix the end of the tape to the side of the box and push the box so that it passes under the dispenser
- 5) Pull down the dispenser after the box has completely been passed under.
The tape will automatically be cut.
- 6) Press down on the tape so that it is securely attached to the box surface.

Table Mounted Product

To operate this product:

- 1) Align the center of the box on the centerline marked on the mat and slide it until it hits the bumper
- 2) Adjust the height of the tape dispenser by lowering it until the setting bar hits the box, stopping it from going any lower. Secure it back into place.
- 3) Place whole hand under tape (catching the sticky side of the tape on the hand) and lift.
- 4) Pull out the tape and secure it to the opposite side of the box. The tape should now be stretched across the box, but not sealing it.
- 5) Starting from where the tape is secured, use your hand to smooth the tape down onto the box. This will create tension between the tape on the box and the dispenser.

6) Line up the hand with the blade and push down and away on the tape to cut it (similar to the motion of using a small tape dispenser).

7) Affix the loose end of the tape to the end of the box to seal it closed.

Tape Stamper Product:

This product is made up of a unit that keeps the box stable and also serves as a storage container for the tape stamper and charging pad.

To operate this product:

- 1) Pull apart the two halves of the base unit.
- 2) Place the two halves on opposite corners of the box if necessary to keep the box from sliding.
- 3) Place a hand under the strap of the tape stamping unit.
- 4) Align the unit where tape should be applied
- 5) Press down on the button (under your hand) to stamp a piece of tape onto the box.

Automated Tape Feeder Product:

To operate this product:

- 1) Adjust the angle of the easel to allow access to the top of the box to be taped.
- 2) Place the box onto the easel and adjust the side sliding panel so that it holds the box in place. The side panel can be used on either the left or right hand side of the device.

- 3) Place the dispenser on the side of the table so that the lip hangs over the side.
 - 4) Press the dispense button and tape will come out while the button is pressed. The original intent was for a three inch length of tape to be dispensed when the button is pressed once, though it was not manufactured like this.
 - 5) Press the button as many times as necessary to obtain the necessary length of tape.
 - 6) Press the cut button to cut the tape.
 - 7) Place the cut length of tape onto the box to seal it.
-
- Have the user complete the product ranking survey.

APPENDIX T

ORGANIZATIONS CONTACTED DURING RECRUITMENT

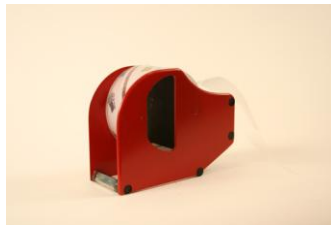
A number of different organizations were contacted to seek people interested in participating in the study. A full list of the organizations follows:

- Catea Consumer Network (CCN) - <http://www.catea.gatech.edu/ccn/ccn.php>
- Developmental Disabilities Ministry – <http://www.ddmga.org>
- United Cerebral Palsy of Atlanta - http://www.ucp.org/ucp_local.cfm/63
- Arthritis Foundation Georgia Chapter - <http://www.arthritis.org/chapters/georgia>
- Atlanta Post Polio Association - <http://www.atlantapostpolio.com>
- Access Disabled Assistance Program for Tech Students (ADAPTS) -
<http://www.adapts.gatech.edu/>
- The Whistle - <http://www.whistle.gatech.edu/>
- The A.G. Rhodes Home - Atlanta and Marietta - <http://agrhodes.com>
- Rainbow Senior Services - <http://rainbowseniorservices.com>
- Lenbrook Retirement Community - <http://lenbrook-atlanta.com>
- Georgia Institute on Aging - agingservicesga.org
- Senior Citizen Services of Metropolitan Atlanta - <http://www.scsatl.org>

APPENDIX U

PRODUCT RANKING SURVEY

Instructions: Please rank the products from best to worst based on your overall opinion. Start with 1 for the best, 2 for the next best and go up to 8 for the worst. Choose a unique rank for each product (**there are no ties**).

















APPENDIX V

CORRELATIONS WITH DEXTERITY MEASURES

Several different measures of dexterity were measured for each evaluator. These measurements were:

- DASH - self report questionnaire of upper body limitations
- Nine Hole Peg Test (NHPT) - test of fine finger dexterity
- Tip Pinch Strength
- Key Pinch Strength
- Grip Strength

The values of each test collected from the evaluators was correlated with the others tests to see how they might be related (Table V.1). Pearson's r and Spearman's ρ were used for the comparisons. Pearson's r assumes that the data is interval or ratio. That assumption is true for the NHPT, Tip Pinch, Key Pinch and Grip Strength and Task Duration but it is not true for the DASH and all of the survey scores or the device ranking. Often only Person's r is used because the values of these two tests are very close, provided there aren't many outliers in the data. Both values are presented in Table V.1.

Table V.1. Correlations between dexterity measurements

	Spearman's ρ	p value	Pearson's r	rsq	sig
DASH - NHPT	0.607	0.005	0.583	0.339	0.004
DASH - TIP Pinch	-0.618	0.004	-0.668	0.446	0.001
DASH -Key Pinch	-0.436	0.055	-0.485	0.236	0.022
DASH - Grip Strength	-0.525	0.017	-0.525	0.275	0.012
NHPT - Tip Pinch	-0.479	0.0325	-0.443	0.196	0.039
NHPT - Key Pinch	-0.329	0.157	-0.431	0.186	0.045
NHPT - Grip Strength	-0.241	0.306	-0.429	0.184	0.046
Tip Pinch - Key Pinch	0.775	< .001	0.774	0.599	< .001
Tip Pinch - Grip Strength	0.748	< .001	0.647	0.419	0.001
Key Pinch - Grip Strength	0.655	0.002	0.679	0.462	< .001

The correlations between Tip Pinch, Key Pinch and Grip Strength measurements are strong. One of these can be used for later comparisons since any one of them is likely to give very similar results (although the r squared (rsq) value of the correlations between the combinations of these three seems to indicate that only about half of the variance between them is shared). The correlation between the DASH and NHPT is moderate (.607) and the r squared value is low (0.34), so it seems like these are probably mostly measuring different things. Analysis of the effects of dexterity level will focus on:

- DASH - the DASH is less strongly correlated to the NHPT and the other measurements indicating that it measures unique aspects of dexterity limitations.
- NHPT - it is less strongly correlated to the DASH or other measures and so is likely to measure different aspects of dexterity than the others.
- Key Pinch - the Key Pinch, Tip Pinch and Grip Strength measurements are all highly correlated and are likely to provide similar results. Of the three, Key Pinch is used because it is the least strongly correlated to the DASH and NHPT compared to Tip Pinch or Grip Strength.

The NHPT, DASH and Key Pinch tests were compared with the Total score to investigate whether an evaluator's level of dexterity related to the evaluation of a device. Table V.2 shows the results of the correlations between the dexterity measures and the Total evaluation scores. Keep in mind that for the NHPT and DASH, higher values indicate a more severe dexterity limitation. For the Key Pinch test, lower values indicate more severe dexterity limitations. We can see from the table that in most cases, there is weak to moderate correlation between the level of dexterity limitation and how each of the devices was scored. In the case of the Conveyor Product, it was scored higher as the severity of the evaluator's dexterity limitation increased (i.e. a positive correlation with

NHPT and DASH and a negative correlation with Key Pinch).

Table V.2. Correlations between Dexterity measures and Total score for each device

Input	Products	NHPT	DASH	Key Pinch
none	Conveyor Product	0.343	0.467	-0.181
none	Tape Puller Product	-0.263	-0.096	0.064
tool	Cabinet Mounted Product	-0.308	0.100	-0.093
tool	Table Mounted Product	-0.193	0.092	0.115
OT	Powered Pole Product	-0.245	0.183	0.069
OT	Wall Mounted Product	-0.299	0.124	0.305
user	Tape Feeder Product	0.001	0.476	-0.253
user	Tape Stamper Product	0.094	-0.023	-0.360
	Standard Dispenser	-0.155	0.199	0.053

The efficiency of the devices was compared to the total usability data to investigate whether the efficiency of a device significantly is related to total usability.

Table V.2 shows the correlation between Usability and Efficiency. There is a weak but significant correlation between Usability and Efficiency. As the time needed to perform a task increases, the surveyed level of effectiveness and satisfaction dropped. But this correlation is noisy and seems only true up to a point. In these devices, Task times over approximately 100 seconds resulted in fairly uniform low scores. However, if the task time is less than about 100 seconds, then the device is nearly as likely to get a high evaluation as it is to be get a low evaluation. So, while good efficiency is important, there are other factors that can have a stronger influence on how effective or satisfactory a user will consider a device.

Table V.3. Correlation between Total Score and Efficiency

	Spearman's rho	p value
Total - Efficiency	-0.262	0.002

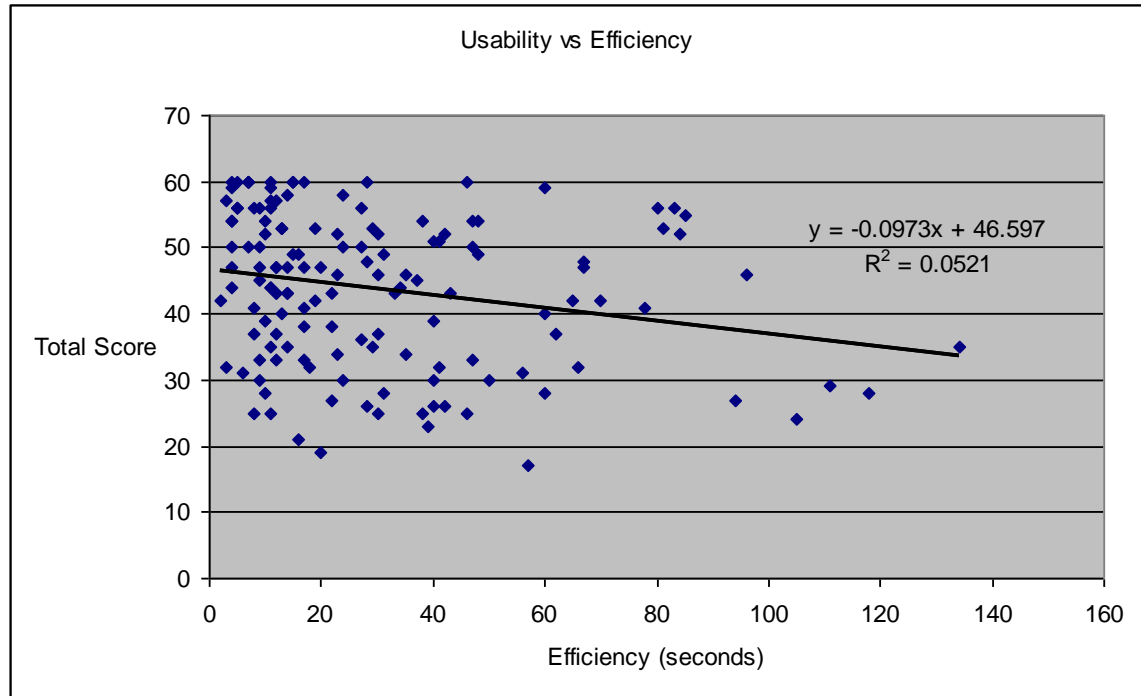


Figure V.1 Scatter plot of Usability vs Efficiency

The evaluator's immediate opinion of the device was compared with the overall ranking to verify that it corresponded to the way that the device was Ranked overall. This can be examined by looking at the correlation between the user's immediate opinion about the device just after using it (measured by question 13) and the Total score (total usability). There was a strong positive correlation between the evaluator's immediate opinion of the device just after completing the task and the Total score. The total score and the answer to Q13 move in the same direction. The analysis results can be seen in Table V.4 and Figure V.2.

Table V.4. Correlation between Total score and immediate opinion of the device

	Spearman's rho	p value
Total - Q13	0.872	<.001

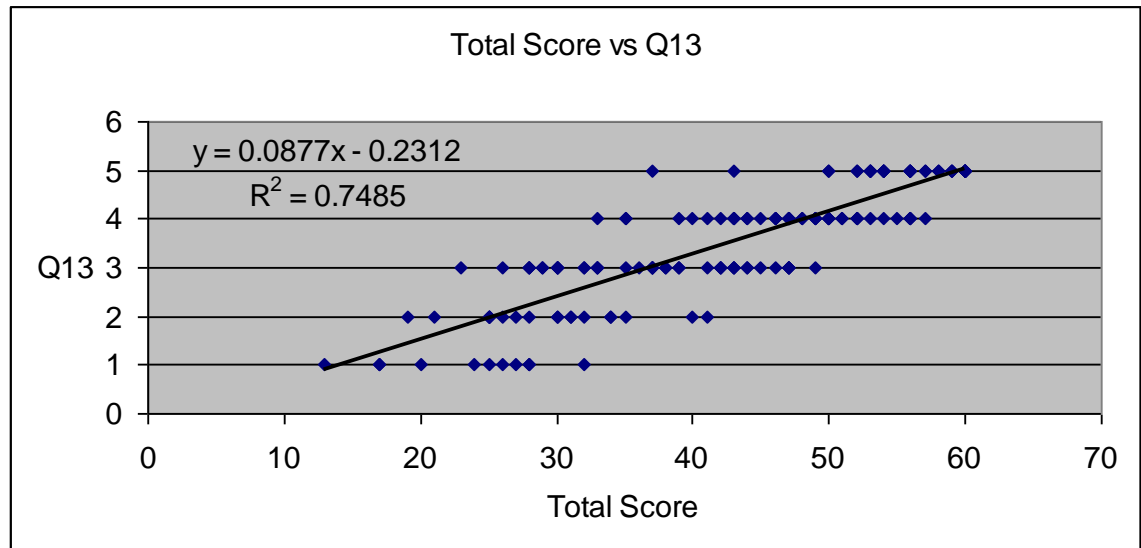


Figure V.2. Scatter plot of Total score vs immediate opinion of the device

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